DEFINITION OF AVIATION TURBINE FUEL CONTAMINATION UNDER SIMULATED COMBAT CONDITIONS

FINAL REPORT
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by

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JP-4 drain samples were obtained from Army aircraft, tank trucks, and other points in the fuel supply system at six field exercises under intensive training conditions. The samples were analyzed for particulate contaminants and compared to the contaminants package for test fluids used in aviation gas turbine engine component and systems qualification testing under AV-E-8593B. Results indicate that (a) the vast majority of samples had contamination concentration levels several orders of magnitude less than the AV-E-8593B package, (b) an

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20. ABSTRACT

unexpectedly high number of aircraft drain samples (roughly 7 percent) and numerous points in the refueling systems showed concentrations far exceeding this package. Both the quantities and chemical nature of these particulate contaminants indicate that the AV-E-8593B package is realistic and representative of contamination which can occasionally occur in field Army operations. The utilization of this contaminants package therefore provides suitably stringent criteria for bench test qualification of aviation gas turbine engine fuel system components.

FOREWORD

The work reported herein was conducted by the U.S. Army Fuels and Lubricants Research Laboratory, located at Southwest Research Institute, San Antonio, Texas, under contract DAAG53-76-C-0003.

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I. INTRODUCTION

Aviation fuel contamination traditionally manifests itself in some form of in-flight malfunction, or, at best, in power loss or startup malfunction during ground operations. The purpose of all engine/fuel specification requirements is to minimize the likelihood of fuel-related incidents. Requirements can become more severe and less realistic with time to the extent that pass/fail criteria may be challenged by either fuel refiners or engine/component manufacturers. This process of challenge and review of requirements often proves beneficial to both industrial and military interests who share a common goal of maximum systems performance at minimum cost.

The contaminant package for test fluids used in aviation gas turbine engine component and systems qualification testing under AV-E-8593B has come under some criticism for being unrealistically severe. This in itself would not be grounds for relaxation of contaminant size/type criteria since qualification testing must be severe to provide accelerated representation of component life expectancy. A more pertinent and significant question is whether or not the AV-E-8593B contaminant package (see Table 1) is now representative of the type of contaminants encountered in field Army aviation operations, since this package has evolved over the years with ingredients being added as a result of specific military occurrences or operating environments.

Thus there is a basis for a dual argument, quantity and character, for redefinition of this contaminant test package. Such action, however, should be based upon exact

TABLE 1. FUEL CONTAMINANT PACKAGE FOR AV-E-8593B ENGINE COMPONENT QUALIFICATION TESTING

Contaminant	Particle size, μm	Quantity, g/1000 gal
Ferrous-Ferric Iron Oxide (Fe_3O_4, Black color, Magnetite)	0-5	14.0
Ferric Iron Oxide (Fe_2O_3, Hematite)	0-5	14.5
Ferric Iron Oxide (Fe_2O_3, Hematite)	5-10	1.5 (30)*
Crushed Quartz	150- 300	1.0
Crushed Quartz	300- 420	1.0
Crushed Quartz	420-1000	1.75
Crushed Quartz	1000-1500	0.25 (4)*
Prepared dirt conforming to A.C. Spark Plug Co. Part No. 1543637 (Coarse Arizona road dust)	Mixture as follows: 0-5 (12%) 5-10 (12%) 10-20 (14%) 20-40 (23%) 40-80 (30%) 80-200 (9%)	(8.0)*
Cotton linters	Prime cotton linters, First Cut Staple No. 7 (U.S. Department of Agriculture Grading Standards) as ground in a Wiley Mill and screened through a 4 mm screen	0.1
Crude napthenic acid		0.03% by vol
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 parts per million of total solids.	4 parts by weight of NaCl 96 parts by weight of H_2O	0.01% by vol entrained
*Sub-total		

knowledge of the spectrum of contaminants actually encountered by Army aircraft under realistic conditions. A reasonable approach was to collect representative fuel samples during both routine and intense operational situations. During May 1976–March 1977, representatives of the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) collected and analyzed some 219 samples from seven diverse Army aviation activities. One of these, at Ft. Hood, Texas, may be considered more-or-less routine, while the others were the sites of intense training operations. These are detailed in Tables 2 through 13 in Section IV. In addition to aircraft samples, it was considered pertinent to obtain samples at key points in the fuel supply systems (e.g., underground storage tanks, tank trucks, railcars, etc.).

II. FIELD SAMPLE COLLECTION

In April 1976, formal permission was secured from Headquarters, Forces Command (FORSCOM), Fort McPherson, Georgia, to collect JP-4 fuel samples from aircraft and other fuel supply points participating in the following exercises held during 1976-1977:

SOLID SHIELD
BRAVE SHIELD XIV
BRAVE SHIELD XV
REFORGER*
GALLANT CREW

In addition, coordination with cognizant authorities at Fort Hood, Texas and Fort Bliss, Texas resulted in the securing of samples from these two posts under both routine and special training exercise situations.

Prior to obtaining samples, familiarization with various helicopter fuel systems was accomplished at Corpus Christi Army Depot (CCAD), Corpus Christi, Texas where the fuel systems of the UH-1, AH-1, OH-6, and OH-58 were made available to AFLRL technical personnel, and aircraft drain system operations and mechanisms were explained. Based upon the knowledge obtained during this familiarization exercise, the following technique for sample collection was developed:

(a) Clean around aircraft fuel sump drain to remove all foreign matter.

(b) Open sample container (525-ml Nalgene linear polyethylene bottle) while in place under sump drain.

(c) Activate drain as necessary to fill sample bottle.

(d) When bottle is full, place cap on container while in place under sump drain to avoid inclusion of foreign material.

(e) Record aircraft registration number, type, sampling point, last aircraft refueling location, type of refueling, and type of mission flown.

(f) Return sample immediately to AFLRL for analysis.

This sampling technique was the procedure used by AFLRL personnel at all locations.

*Required coordination with Headquarters USAREUR.

III. LABORATORY ANALYSIS

Each sample was analyzed sequentially as follows:

Step 1. Visual Inspection (see Figure 1)–for a general estimate of the degree and type of contamination.

Step 2. Tyndall Cone (see Figure 2)–a light-scattering technique for qualitative evaluation of particle size distribution of suspended material. A light beam is projected into the sample through the bottom of the sample vial. Particle reflectance as seen in a darkened room permits estimation of particle size and degree of contamination. The type of filtration required can be determined.

Step 3. Cascade Filtration (see Figure 3)–The total fuel sample is filtered vertically through a stacked column of filter elements of decreasing porosity. For those samples deemed relatively clear, only two porosities, 8 and 0.45 μm, were used; for samples having higher particulate content, stacked filters of 1000, 500, 300, 102, 52, 26, 8, and 0.45 μm were used. The 8- and 0.45-μm filters were cellulose acetate and the others were nylon mesh.

Step 4. Gravimetric Analysis (see also Figure 3)–The filters were heptane rinsed and dryed. The net weight increase of each filter was recorded. This, plus knowledge of each filter's porosity, resulted in mass distribution histogram data for the select particle size differentials.

Step 5. Photomicrographic Analysis (see Figure 4)–Filter elements were examined under a microscope (20-60X) and those having significant contaminant were photographed at 4X.

FIGURE 1. VISUAL INSPECTION

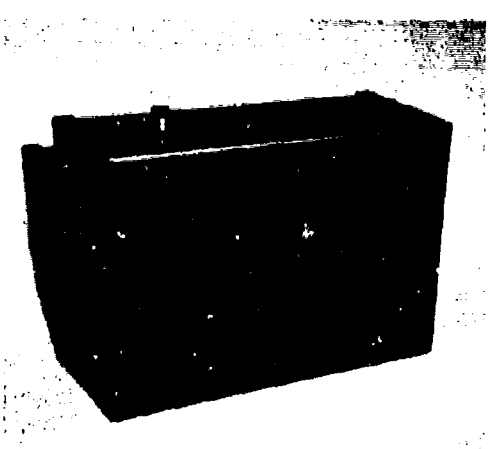


FIGURE 2. TYNDALL CONE APPARATUS

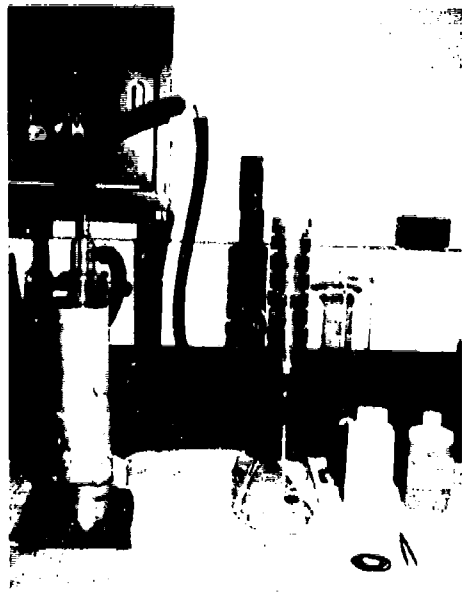


FIGURE 3. CASCADE FILTRATION APPARATUS

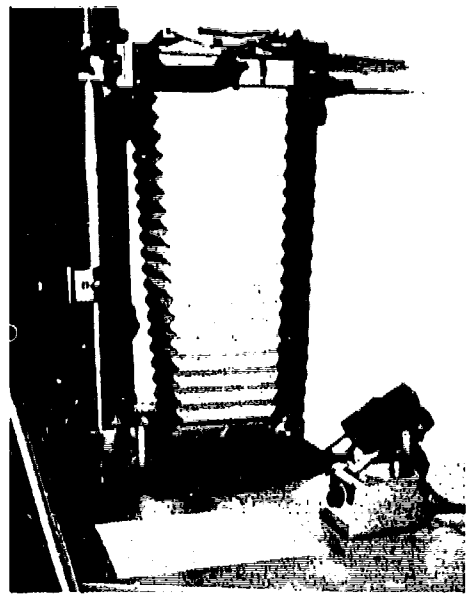


FIGURE 4. PHOTOMICROGRAPHIC APPARATUS

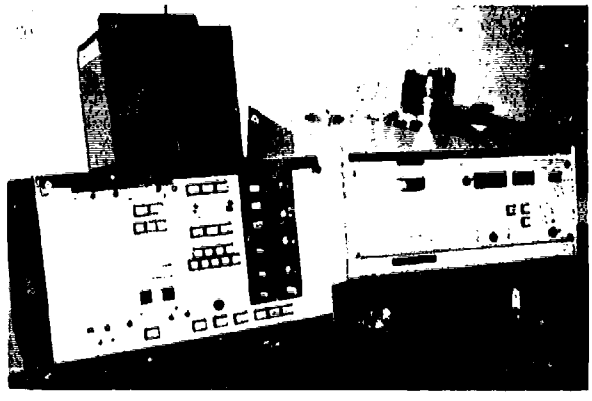


FIGURE 5. X-RAY FLUORESCENCE SPECTROMETER

Step 6. X-Ray Fluorescence Analysis (see Figure 5)—All filters were subjected to energy dispersive X-ray fluorescence analysis (XRF), a nondestructive technique for *elemental* assay. Virtually all elements can be quantitatively identified by XRF. The significant elements detected were iron, aluminum, silicon, phosphorus, sulfur, calcium, chromium, titanium, copper, and zinc. From the distribution of these elements, estimation of the mineralogical and metallic makeup can be made which facilitate confirmation by more sophisticated methods.

Step 7. X-Ray Diffraction - Selected contaminant materials were removed from some of the filters and analyzed by X-ray powder diffractometry. The diffraction patterns were compared to ASTM powder data file standards. Compound composition and crystalline structure were then determined.

Figure 6 presents a flow schematic for the above analysis sequence.

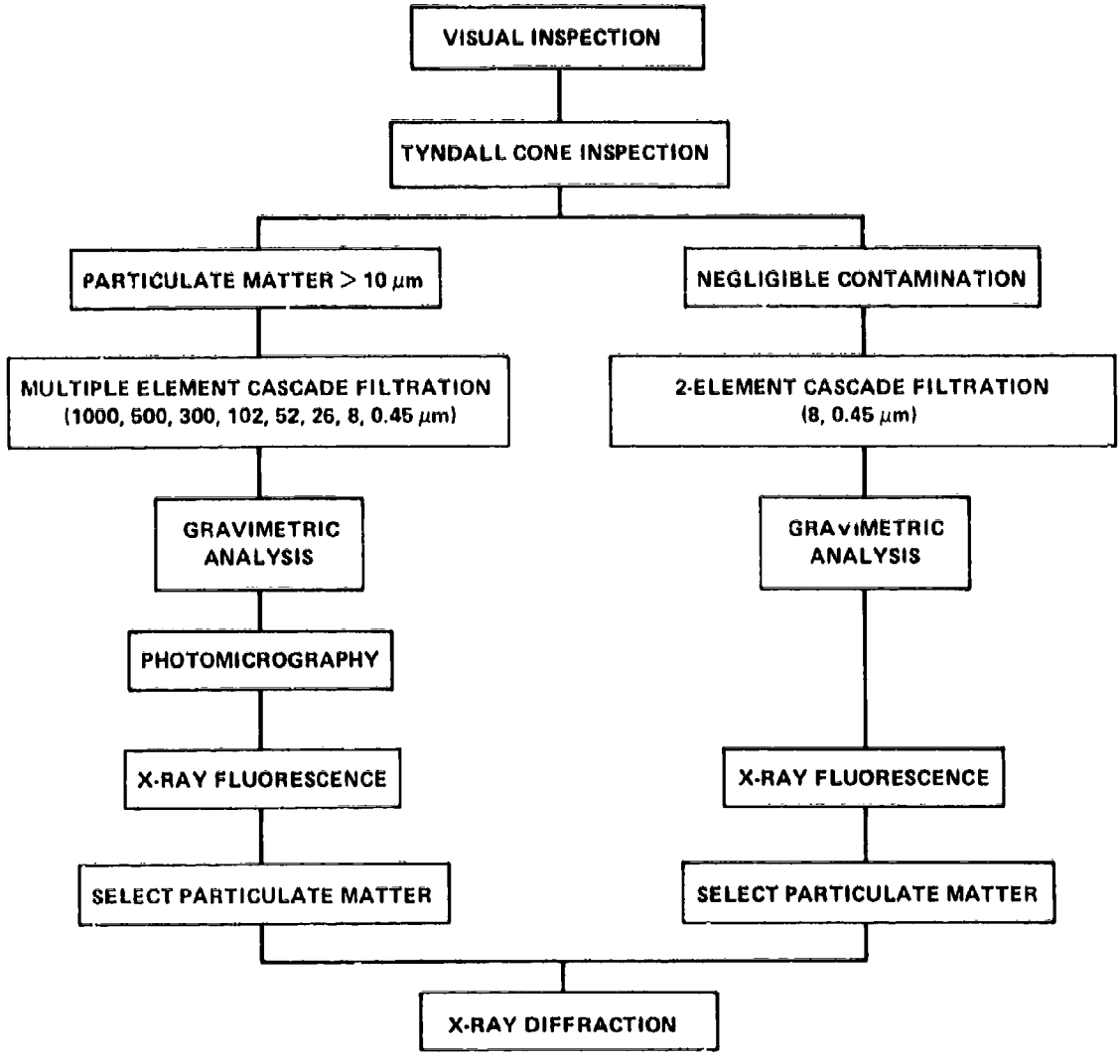


FIGURE 6. CONTAMINANTS ANALYSIS SEQUENCE FOR JP-4 SAMPLES

IV. RESULTS OF ANALYSIS

JP-4 particulate contaminants data for the several operational sites are summarized in Tables 2 through 13. Lab sample numbers, sample dates, and aircraft/unit identification are self-explanatory. Particulate concentrations (in grams per thousand gallons) have been calculated and reported as the oxides of the metals even though the element is determined by X-ray fluorescence. Reporting all iron as Fe_2O_3, all silicon as SiO_2 (quartz), all aluminum as Al_2O_3, and all calcium as CaO is the only possible way to permit comparison of data to AV-E-8593B values.

Numbers in parentheses (30.0, 4.0, and 8.0) at the bottom of certain columns represent the AV-E-8593B levels for iron oxides, silicon dioxide, and "road dust" (see Table 1).

A. Hood AAF, Fort Hood, Texas (1976)

Prior to participating in scheduled Army field training exercises, AFLRL personnel took 11 drain samples from aircraft at Hood AAF. These aircraft were either used in routine training operations with Second Armored Division stationed at Fort Hood, or were transient aircraft undergoing periodic maintenance. Visual inspection and subsequent filtration and gravimetric analysis (see Section III) showed contaminant levels (see Table 2) for all samples to be lower than AV-E-8593B levels, so no cascade filtrations were performed. This was intended as a field/lab familiarization exercise as well as to provide initial data.

All aircraft samples were taken at belly sump drain points, since sampling from other points in the aircraft would have entailed disassembly of internal fuel system components and consequent interruption of the air support mission. All sump samples* actually represent maximum particulate contamination accumulated between preflight or maintenance sump drain operations.

B. Oak Grove AAF, Solid Shield, Fort Bragg, North Carolina (1976)

In this first sampling from a formal exercise, relatively low contamination was found in 26 samples from active aircraft and 3 samples from nozzle and bladder/sump drains at the fixed fuel point at Oak Grove AAF (see Table 3). For this reason, no cascade filtration was performed.

C. New Mexico ANG Training Exercise, Biggs AAF (1976)

Three samples in Table 4 (6466, 6476, and 6486) had such high contaminant concentrations that cascade filtration was indicated. Data for this analysis are given in Table 5. These three samples were collected from the Biggs (Fort Bliss) AAF underground fuel storage complex† Samples 6466 and 6476 were obtained with a sampling thief from tanks three and five, approximately 1 inch above each tank bottom. All tanks had been cleaned and filter elements changed February 1976, some 90 to 120 days prior to AFLRL sampling. Sample 6486 was taken immediately downstream of the filtration system serving tanks 3 and 4 jointly. Note that tanks 4 and 6 center samples (6471, 6481) had far less contaminant as compared to the other samples in Table 5, but still had quite high levels as compared to most aircraft samples. The sample taken immediately downstream of the joint tank 5/6 filtration system (6493, Table 4) showed virtually no contamination.

*LF left forward; RF right forward; LR left rear; RR right rear; LM left main; RM right main; F forward, A aft.
†Under control of Directorate of Industrial Operations Petroleum, Oils, Lubricants (DIO-POL).

TABLE 2. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS AT FT. HOOD, TEXAS (HOOD AAF)

Sample no.	Date	Aircraft reg no.	Aircraft type	Unit	Particulate concentration, g/1000 gal[a]						Sump
					Fe[b]	Si[b]	Al[b]	Ca[b]	Total Non-Ferrous Oxides[c]	Total Particulate Contaminants	
4442	5-7-76	71-20474	OH-58A	2nd Armored Div	Nil[d]	Nil	Nil	Nil	Nil	Nil	–
6443	5-7-76	73-21850	UH-1H	2nd Armored Div	0.021	0.034	0.028	Nil	0.062	0.083	LF
6444	5-7-76	73-21850	UH-1H	2nd Armored Div	Nil	0.033	0.057	Nil	0.090	0.090	RF
6445	5-7-76	73-21850	UH-1H	2nd Armored Div	0.025	Nil	Nil	Nil	Nil	0.025	LF
6446	5-7-76	67-15654	AH-1G	2nd Armored Div	0.103	1.020	0.363	0.522	1.905	2.008	F
6447	5-7-76	68-16991	OV-1	2nd Armored Div	0.091	0.340	Nil	Nil	0.034	0.125	–
6448	5-7-76	68-13820	UH-1H	2nd Armored Div	0.031	Nil	Nil	Nil	Nil	0.031	LF
6449	5-7-76	70-16093	AH-1G	2nd Armored Div	Nil	Nil	Nil	Nil	Nil	Nil	A
6450	5-7-76	67-18491	CH-47B	Ft. Sill, OK	0.031	Nil	Nil	Nil	Nil	0.031	–
6451	5-7-76	70-16478	UH-1H	Ft. Sam Houston, TX	Nil	Nil	Nil	Nil	Nil	Nil	LF
6452	5-7-76	70-16478	UH-1H	Ft. Sam Houston, TX	0.014	0.069	Nil	Nil	0.969	0.083	RF
AV-E-8593B concentration					(30.0)	(4.0)			(8.0)	(42.0)	

Notes: Numbers in parentheses are designated concentrations (g/1000 gal) for specific constituents of AV-E-8593B test fluid.

[b] Calculated as Fe_2O_3, SiO_2, Al_2O_3, and CaO, respectively.

[a] All particulate matter less than 10μm.

[c] Total Non-Ferrous Oxides = SiO_2 + Al_2O_3 + CaO (principal constituents of A.C. 1543637 prepared dirt)

[d] Nil – Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal.).

Contaminant concentration for the five extreme cases (Table 5) are expressed in g/1000 gallons for consistent comparison to the preceding tables, and particle size distribution in micrometers (μm)* has been determined by gravimetric and X-ray fluorescence analyses which give net particulate mass and predominant elements, respectively. Determination of compound class from element distribution was quite straightforward. For sample 6466, iron compounds comprised 99 to 100 percent of the mass down to 300 μm, and comprised 80 to 90 percent thereafter to 8 μm. The balance was silicon, and subsequent X-ray diffraction analysis confirmed that all iron was present as Fe_2O_3, Fe_3O_4, or FeO(OH) and all silicon as SiO_2. The same was true for sample 6486, except that more SiO_2 was present in the 8- to 500-μm range. Sample 6486 had, in addition to iron oxides and quartz, significant amounts of calcium and aluminum. Again, X-ray diffraction confirmed these elements to be present as calcium aluminum silicates ($CaAl_2Si_2O_8$), a claylike material indigenous to the southwest United States.

Table 6 presents particulate distribution data for the four aircraft having highest contaminant levels from the Fort Bliss (Biggs AAF) operation. No mass distribution data could be obtained for samples 6487 or 6492 since all particulate matter was captured on 8- and 0.45-μm filters and consumed for X-ray diffraction analysis to determine compound class distribution. *It is significant that the values for these samples approached specification levels and came from aircraft having recently completed several NOE missions over desert terrain.*

D. BRAVE SHIELD XIV (1976)

All samples for BRAVE SHIELD XIV were taken at the single fixed refueling point at Yakima Firing Range, Washington. Data are given in Table 7. Again, contaminant levels for 23 samples from aircraft belly drains and 3 samples from refueling trucks were found to be below specification levels. For this reason, no subsequent gravimetric analysis was deemed necessary.

E. REFORGER, Germany (1976)

Advanced coordination with USAREUR resulted in an AFLRL staff member participating in this OCONUS exercise. Some 38 aircraft bellydrain samples (see Table 8) were taken at several aircraft deployment positions. In addition, numerous samples were taken upstream and downstream of individual bladder-filtration units and at exit nozzle points. Since one of the points of supply prior to the hardpoint refueling stations was a railroad tank car, it was possible to obtain samples from the tank car itself and after filtration through the discharge filter separator. Sample 6600 shows a total nonferrous oxide level of 16.566. Of this quantity, 15.806 was found to be composed of a silicon compound. This was attributable to a single tuft of inorganic material, and cascade filtration was therefore not required. The source of the tuft remains unknown; it was downstream of the filter separator. It is quite likely that subsequent filtration would have removed this item from the fuel flowstream.

Three aircraft samples, 6594, 6603, and 6614, were found to have sufficiently high particulate concentrations to warrant cascade filtration and subsequent X-ray difraction analysis for compound class. These are given in Table 9. For sample 6594 (AH-1G No. 70-16045), it was found that iron oxide particulates were distributed across the total range of filter porosities. Quartz and calcium silicates took the form of rather fine particles in the 8- to 52-μm range while zinc compounds (likely from paint) were in rather large chips of sizes in excess of 1000 μm. For 6603 (OH-58A No. 71-20497), enormous quantities of iron oxides and zinc compounds of relatively large particle

*Commonly referred to as microns (μ).

TABLE 5. PARTICULATE SIZE, MASS, AND CLASS DISTRIBUTION FOR BIGGS AAF UNDERGROUND STORAGE TANK SAMPLES

Sample no.	Location	Compound class	Estimated particulate concentration, g/1000 gal								
			≥1000 μm	500-1000 μm	300-500 μm	102-300 μm	52-102 μm	26-52 μm	8-26 μm	0.45-8 μm	Total
6466	Biggs AAF DIO-POL Tank 3 Bottoms	Iron oxides[a]	203	100	58	96	97	85	70	Nil	709
		Quartz[b]	Nil	Nil	Nil	8	8	16	13	Nil	45
6476	Biggs AAF DIO-POL Tank 5 Bottoms	Iron oxides[a]	991	270	270	1890	1060	1040	196	Nil	5717
		Quartz[b]	Nil	Nil	23	354	199	195	37	Nil	808
6486	Biggs AAF DIO-POL Nozzle Downstream of Tank 3/4 Filter	Iron oxides[a]	Nil	Nil	Nil	135	9	Nil	Nil	Nil	144
		Quartz[b]	29	142	287	203	13	Nil	Nil	Nil	674
		Calcium silicates[c]	2	9	19	13	1	Nil	Nil	Nil	44
6471	Biggs AAF DIO-POL Center of Tank 4	Iron oxides[a]	d	d	d	d	d	d	1	d	1
		Quartz[b]	d	d	d	d	d	d	2	d	2
		Calcium silicates[c]	d	d	d	d	d	d	1	d	1
6481	Biggs AAF DIO-POL Center of Tank 6	Iron oxides[a]	d	d	d	d	d	d	8	d	8
		Quartz[b]	d	d	d	d	d	d	2	d	2
		Calcium silicates[c]	d	d	d	d	d	d	1	d	1

[a] As Fe_2O_3.
[b] As SiO_2 (α-quartz).
[c] As $CaAl_2Si_2O_8$.
[d] All particulate matter collected on 8-μm filter and consumed during XRD analysis.

TABLE 6. PARTICULATE SIZE, MASS, AND CLASS DISTRIBUTION FOR BIGGS AAF–REFUELED AIRCRAFT SAMPLES

Sample no.	Aircraft (unit)	Compound class	Estimated particulate concentration, g/1000 gal								
			≥1000 μm	500-1000 μm	300-500 μm	102-300 μm	52-102 μm	26-52 μm	8-26 μm	0.45-8 μm	Total
6496	OH-58A, 71-20667 (3rd Air Cav)	Iron oxides[d]	Nil	Nil	0.18	0.07	Nil	Nil	Nil	Nil	0.25
		Quartz[e]	Nil	Nil	0.05	1.15	0.15	Nil	Nil	Nil	1.35
6499	AH-1G, 70-15953[a] (3rd Air Cav)	Iron oxides[d]	Nil	0.02	0.20	0.02	Nil	Nil	Nil	Nil	0.24
		Quartz[e]	Nil	0.27	1.10	0.40	Nil	Nil	Nil	Nil	1.77
6487	AH-1G, 71-20984[b] (3rd Air Cav)	Iron oxides[d]	g	g	g	g	g	g	1.00	g	1.00
		Quartz[e]	g	g	g	g	g	g	10.03	g	10.03
		Calcium silicates[f]	g	g	g	g	g	g	3.94	g	3.94
6492	AH-1G, 71-20984[c] (3rd Air Cav)	Iron oxides[d]	g	g	g	g	g	g	0.57	g	0.57
		Quartz[e]	g	g	g	g	g	g	2.27	g	2.27
		Calcium silicates[f]	g	g	g	g	g	g	0.95	g	0.95

[a] Front Drain.
[b] Aft Drain.
[c] Front Drain.
[d] As Fe_2O_3.
[e] As SiO_2 (α-Quartz).
[f] As $CaAl_2Si_2O_8$.
[g] All particulate matter collected on 8-μm filter and consumed during XRD analysis.

TABLE 7. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XIV

Sample no.	Date	Aircraft reg no.	Aircraft type	Unit	Particulate Concentration, g/1000 gal.[a]						Sump
					Fe[b]	Si[b]	Al[b]	Ca[b]	Total Non-Ferrous Oxides[c]	Total Particulate Contaminants	
6545	8-23-76	74-22429	UH-1H	USAASL, REDCOM	0.164	Nil	Nil	0.542	0.542	0.706	LF
6546	8-23-76	74-22495	UH-1H	USAASL, REDCOM	0.243	0.648	0.518	0.212	1.378	1.621	LF
6558	8-23-76	---	---	5th Air Cav	0.144	Nil	Nil	Nil	Nil	0.144	—
6561	8-23-76	---	---	5th Air Cav	0.519	0.798	Nil	Nil	0.798	1.317	—
6566	8-23-76	---	---	5th Air Cav	0.048	1.299	Nil	Nil	1.299	1.347	—
6551	8-23-76	68-15451	UH-1H	"B" Troop, 5th Air Cav	0.148	Nil	Nil	Nil	Nil	0.148	LF
6547	8-23-76	71-20806	OH-58A	"C" Troop, 5th Air Cav	0.199	Nil	Nil	0.014	0.014	0.213	—
6549	8-23-76	71-20444	OH-58A	"C" Troop, 5th Air Cav	2.018	2.266	2.743	0.236	5.245	7.263	—
6550	8-23-76	71-21087	OH-58A	"C" Troop, 5th Air Cav	1.175	1.431	0.663	0.206	2.300	3.475	—
6548	8-23-76	68-15769	UH-1H	"C" Troop, 5th Air Cav	0.113	Nil	Nil	0.028	0.028	0.141	LF
6553	8-23-76	69-15171	UH-1H	540 Avn Co, Wash Ang	0.215	Nil	Nil	0.056	0.056	0.271	LF
6552	8-23-76	71-20215	UH-1H	116th Avn Co	0.089	Nil	Nil	Nil	Nil	0.089	LF
6560	8-23-76	68-16239	UH-1H	116th Avn Co	0.104	Nil	Nil	Nil	Nil	0.104	LF
6562	8-23-76	66-00856	UH-1H	116th Avn Co	0.141	Nil	Nil	Nil	Nil	0.141	LF
6563	8-23-76	65-9967	UH-1H	116th Avn Co	0.178	Nil	Nil	0.050	0.050	0.228	LF
6556	8-23-76	66-17064	UH-1H	116th Avn Co	0.124	Nil	Nil	Nil	Nil	0.124	LF
6554	8-23-76	71-20763	OH-58A	9th Div	0.294	0.624	Nil	0.048	0.673	0.967	—
6555	8-23-76	71-20586	OH-58A	9th Div	0.694	0.700	0.401	0.087	1.188	1.882	—
6557	8-23-76	69-16723	UH-1H	9th Div	0.086	Nil	Nil	Nil	Nil	0.086	LF
6559	8-23-76	70-15254	OH-58A	9th Div Aty	0.077	Nil	Nil	Nil	Nil	0.077	—
6564	8-23-76	70-16384	UH-1H	9th Avn Bn	0.066	Nil	Nil	Nil	Nil	0.066	LF
6568	8-23-76	66-16627	UH-1H	9th Avn Bn	0.077	Nil	Nil	Nil	Nil	0.077	LF
6565	8-23-76	70-15311	OH-58A	"C" Troop, 9th Avn Co	0.165	Nil	Nil	0.035	0.035	0.200	—
6569	8-23-76	66-16616	UH-1H	54th Med Avn Co	0.127	Nil	Nil	0.050	0.050	0.177	LF
6570	8-23-76	70-16381	UH-1H	54th Med Avn Co	0.101	Nil	Nil	0.050	0.050	0.151	LF
6567	8-23-76	73-21786	UH-1H	411th Trans Co	0.124	Nil	Nil	Nil	Nil	0.124	LF
					(30.0)	(4.0)			(8.0)	(42.0)	

Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-E-8593B fluid.

[b] Calculated as Fe_2O_3, SiO_2, Al_2O_3 + CaO.

[a] All particulate matter less than 10 μm.

[c] Total Non-Ferrous Oxides = SiO_2 + Al_2O_3 + CaO.

[d] Nil – Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).

TABLE 8. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR REFORGER

Sample no.	Aircraft reg. no.	Aircraft type	Unit	Particulate Concentration, g/1000 gal.[a]						Sump
				Fe[b]	Si[b]	Al[b]	Ca[b]	Total Non-Ferrous Oxides[c]	Total Particulate Contaminants	
6579	71-20142	UH-1H	"A" Co, 5th Trans Bn	0.112	0.854	Nil[d]	0.026	0.880	0.992	RF
6578	71-20142	UH-1H	"A" Co, 5th Trans Bn	0.216	0.953	Nil	0.039	0.992	1.208	LF
6613	74-22359	UH-1H	"A" Co, 5th Trans Bn	0.049	Nil	Nil	Nil	Nil	0.049	RF
6612	74-22359	UH-1H	"A" Co, 5th Trans Bn	0.178	0.894	Nil	0.122	1.016	1.194	LF
6591	69-15369	UH-1H	"A" Co, 5th Trans Bn	0.098	Nil	Nil	0.029	0.029	0.127	RF
6590	69-15369	UH-1H	"A" Co, 5th Trans Bn	0.129	1.095	Nil	Nil	1.095	2.079	LF
6593	69-15754	UH-1H	"A" Co, 5th Trans Bn	0.111	Nil	Nil	0.025	0.025	0.136	RF
6592	69-15754	UH-1H	"A" Co, 5th Trans Bn	0.074	Nil	Nil	0.042	0.042	0.116	LF
6586	73-21709	UH-1H	"A" Co, 5th Trans Bn	0.098	Nil	Nil	Nil	Nil	0.098	RF
6585	73-21709	UH-1H	"A" Co, 5th Trans Bn	0.123	Nil	Nil	0.029	0.029	0.152	LF
6584	70-15798	UH-1H	"A" Co, 5th Trans Bn	0.130	1.328	Nil	0.050	1.378	1.508	LF
6582	66-19135	CH-47B	"A" Co, 5th Trans Bn	0.429	1.558	0.466	0.151	2.175	2.604	R
6581	66-19135	CH-47B	"A" Co, 5th Trans Bn	0.186	0.791	0.376	0.118	1.284	1.470	L
6580	67-15721	AH-1G	"A" Co, 5th Trans Bn	0.297	2.945	0.549	0.151	3.644	3.941	F
6594	70-16045	AH-1G	"A" Co, 5th Trans Bn	High Particulate Concentration. See Table 9					21.550	F
6583	70-15238	OH-58A	"A" Co, 5th Trans Bn	0.075	Nil	Nil	Nil	Nil	0.075	
6589	68-16977	OH-58A	"A" Co, 5th Trans Bn	0.563	0.473	Nil	0.170	0.643	1.206	
6588	67-17672	UH-1H	"B" Co, 5th Trans Bn	0.228	7.152	Nil	0.113	7.265	7.493	RF
6587	67-17672	UH-1H	"B" Co, 5th Trans Bn	0.237	1.899	Nil	0.038	1.937	2.174	LF
6595	Pol-Rapid Refill Point		"D" Co, 426 S&S Bn	0.122	Nil	Nil	Nil	Nil	0.122	
6596	Pol-Rapid Refill Point		"D" Co, 426 S&S Bn	0.155	Nil	Nil	0.043	0.043	0.198	
6597	Pol-Rapid Refill Point		"D" Co, 426 S&S Bn	0.056	Nil	Nil	Nil	Nil	0.056	
6598	7G1216	Tank Truck	"D" Co, 426 S&S Bn	0.068	Nil	Nil	Nil	Nil	0.068	
6599	007-0-323-9P	Railway tank car	493 S&S Co, 87th Maint Bn	0.102	Nil	Nil	0.037	0.037	0.139	
6600	007-0-323-9P	Railway tank car	493 S&S Co, 87th Maint Bn	0.683	15.806	Nil	0.760	16.566	17.249	
6601	70-15561	OH-58A	175 Av Co, 1st Arm Div	0.360	0.940	0.463	0.107	1.511	1.871	
6602	72-21405	OH-58A	175 Av Co, 1st Arm Div	0.245	Nil	0.346	0.131	0.477	0.722	
6603	71-20497	OH-58A	25 Av Co, VII Corps	High Particulate Concentration. See Table 9					138.900	
6604	70-15172	OH-58A	25 Av Co, VII Corps	0.136	0.658	0.518	0.071	1.247	1.383	
6606	70-15771	UH-1H	25 Av Co, VII Corps	0.087	Nil	Nil	Nil	Nil	0.087	RF
6605	70-15771	UH-1H	25 Av Co, VII Corps	0.072	Nil	Nil	Nil	Nil	0.072	LF
6611	NK02VN	Tank truck	25 Av Co, VII Corps	0.097	Nil	Nil	Nil	Nil	0.097	
6610	68-15755	UH-1H	HHC 2nd Support Com	0.114	Nil	Nil	0.070	0.070	0.184	RF
6609	68-15755	UH-1H	HHC 2nd Support Com	0.095	Nil	Nil	Nil	Nil	0.095	LF
6608	73-21770	UH-1H	HHC 2nd Support Com	0.096	Nil	Nil	0.022	0.022	0.118	RF
6607	73-21770	UH-1H	HHC 2nd Support Com	0.141	Nil	Nil	0.124	0.124	0.265	LF
6618	74-22329	UH-1H	30th Trans Co	0.162	0.988	Nil	0.029	1.017	1.179	RF
6617	74-22329	UH-1H	30th Trans Co	0.133	0.836	0.385	0.038	1.259	1.392	LF
6620	65-12773	UH-1H	30th Trans Co	0.099	Nil	Nil	0.068	0.068	0.167	RF
6619	65-12773	UH-1H	30th Trans Co	0.085	Nil	Nil	Nil	Nil	0.085	LF
6622	69-17126	CH-47C	30th Trans Co	0.332	1.153	0.746	0.364	2.264	2.596	RF
6621	69-17126	CH-47C	30th Trans Co	1.464	5.433	0.849	0.568	6.850	8.314	LF
6623	70-15127	OH-58A	30th Trans Co	0.093	Nil	Nil	0.054	0.054	0.147	RF
6615	71-20838	OH-58A	"B" Troop 2/17 Cav	1.523	2.468	1.501	0.485	4.455	5.978	
6614	71-21031	AH-1G	"C" Troop 2/17 Cav	High Particulate Concentration. See Table 9					54.890	F
				(30.0)	(4.0)			(8.0)	(42.0)	

Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-E-8593B fluid.
[b] Calculated as Fe_2O_3, SiO_2, Al_2O_3 + CaO.
[a] All particulate matter less than 10 μm.
[c] Total Non-Ferrous Oxides = SiO_2 + Al_2O_3 + CaO.
[d] Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).

TABLE 9. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR REFORGER

Sample No.	Aircraft (Unit)	Compound Class	Estimated particulate concentration, g/1000 gal.								
			≥1000 μm	500-1000 μm	300-500 μm	102-300 μm	52-102 μm	26-52 μm	8-26 μm	0.45-8 μm	Total
6594	AH-1G, 70-16045[a] ("A" Co. 5th Trans Bn)	Iron oxides[b]	0.91	0.11	0.23	0.54	0.30	1.24	2.08	Nil	5.41
		Quartz[c]	Nil	Nil	Nil	1.66	Nil	1.24	2.08	Nil	4.98
		Calcium silicates	Nil	Nil	Nil	Nil	Nil	1.65	2.78	Nil	4.43
		Zinc compounds[d]	6.73	Nil	Nil	Nil	Nil	Nil	Nil	Nil	6.73
6603	OH-58A, 71-20497 (25 AV Co., VII Corps)	Iron oxides[b]	16.85	25.99	12.12	10.54	0.66	0.38	Nil	Nil	66.54
		Quartz[c]	0.17	Nil	0.55	0.99	Nil	Nil	Nil	Nil	1.71
		Calcium silicates	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
		Zinc compounds[d]	19.49	25.76	12.06	10.48	0.79	0.49	1.58	Nil	70.65
6614	AH-1G, 71-21031[a] ("C" Troop 2/17 Cav)	Iron oxides[b]	9.80	0.65	Nil	1.97	0.76	1.38	2.58	Nil	17.14
		Quartz[c]	5.10	Nil	Nil	1.58	1.78	4.81	18.05	Nil	31.32
		Calcium silicates	Nil	Nil	Nil	Nil	Nil	0.69	5.15	Nil	5.84
		Zinc compounds[d]	Nil	0.20	Nil	0.39	Nil	Nil	Nil	Nil	0.59

[a]Front drain.
[b]As Fe_2O_3.
[c]As SiO_2 (α-quartz).
[d]ZnO and basic zinc carbonates, nonabrasive to steel.

size were found. These were likely from fuel system rust and ingested paint compounds. For sample 6614 (AH-1G No. 71-21031), contamination stemmed both from iron oxides and quartz. The uniform distribution of both contaminants indicates that the source would be both fuel system rust and clay or sand-like materials ingested into the fuel system during refueling or maintenance operations.

F. BRAVE SHIELD XV, Eglin AFB, Florida (1976)

Thirty aircraft belly-drain samples were taken and two samples from tank trucks used to refuel these same aircraft (see Table 10). In this operation, four individual aircraft (samples 6664, 6665, 6666, and 6667) were found to have significant particulate contamination and were cascade filtered. Data for these four aircraft are given in Table 11. For sample 6664 (OH-58A No. 70-15613), the dominant contaminating material was quartz, the likely source being sand ingested during refueling or maintenance operations. Although contamination was somewhat less for the other three samples, the domination of quartz is still apparent and is not surprising because of the location of this exercise.

G. GALLANT CREW, Fort Hood, Texas (1977)

Two of the 32 aircraft belly-drain samples for this exercise required cascade filtration (see Table 12). At least three other samples (6897, 6898, and 6901) had total nonferrous oxide contamination at a level to warrant cascade filtration, but since no Tyndall Cone effect was observed, this could not be ascertained until after initial filtration. For sample 6895 (CH-47C No. 70-15008), principal contamination stemmed from both quartz and calcium silicates, indicating a mixture of sand and clay from outside sources (see Table 13). To a lesser degree iron oxides were present, again likely from fuel system rust. Sample 6914 (CH-47C No. 70-15019) had roughly the same relative distribution of quartz, calcium silicates, and iron oxides, although at a considerably lower level. Such clay-sand mixtures are indigenous to the Fort Hood area.

TABLE 10. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XV

Sample no.	Date	Aircraft reg. no.	Aircraft type	Unit	Particulate Concentration, g/1000 gal.[a]						Sump
					Fe[b]	Si[b]	Al[b]	Ca[b]	Total Non-Ferrous Oxides[c]	Total Particulate Contaminants	
6642	10-13-76	70-16293	UH-1H	119th Av Co	0.086	0.127	Nil[d]	Nil	0.127	0.213	LF
6643	10-13-76	70-16293	UH-1H	119th Av Co	0.082	0.082	Nil	Nil	0.082	0.164	RF
6644	10-13-76	70-16472	UH-1H	119th Av Co	0.087	0.231	Nil	Nil	0.231	0.318	LF
6645	10-13-76	70-16472	UH-1H	119th Av Co	0.143	0.634	0.070	Nil	0.705	0.848	RF
6646	10-13-76	69-15314	UH-1H	119th Av Co	0.073	0.131	Nil	Nil	0.131	0.204	LF
6647	10-13-76	69-15314	UH-1H	119th Av Co	0.090	0.131	0.054	Nil	0.185	0.275	RF
6648	10-13-76	69-15853	UH-1H	119th Av Co	0.126	0.234	0.080	Nil	0.314	0.440	LF
6649	10-13-76	69-15853	UH-1H	119th Av Co	0.106	0.248	0.062	Nil	0.310	0.416	RF
6650	10-13-76	64-13536	UH-1H	119th Av Co	0.069	0.233	Nil	Nil	0.233	0.302	LF
6651	10-13-76	64-13536	UH-1H	119th Av Co	0.066	0.157	Nil	Nil	0.15[illegible]	0.223	RF
6652	10-13-76	No. 47	Tank truck	119th Av Co	0.054	0.092	Nil	Nil	0.09[illegible]	0.146	Fwd
6653	10-13-76	No. 47	Tank truck	119th Av Co	0.071	0.117	Nil	Nil	0.11[illegible]	0.188	Hose
6654	10-13-76	69-16000	UH-1H	119th Av Co	0.067	0.143	Nil	Nil	0.143	0.210	LF
6655	10-13-76	69-16000	UH-1H	119th Av Co	0.080	0.154	0.061	Nil	0.216	0.296	RF
6656	10-13-76	69-15315	UH-1H	119th Av Co	Nil	0.071	Nil	Nil	0.071	0.071	LF
6657	10-13-76	69-15315	UH-1H	119th Av Co	0.077	0.102	0.026	Nil	0.128	0.205	RF
6658	10-13-76	65-9749	UH-1H	119th Av Co	0.060	0.117	Nil	Nil	0.117	0.177	LF
6659	10-13-76	65-9749	UH-1H	119th Av Co	0.049	0.127	Nil	Nil	0.127	0.176	RF
6660	10-13-76	70-16470	UH-1H	119th Av Co	0.105	0.165	0.093	Nil	0.258	0.363	LF
6661	10-13-76	70-16470	UH-1H	119th Av Co	0.063	0.118	0.080	Nil	0.198	0.261	RF
6662	10-13-76	69-15318	UH-1H	119th Av Co	0.071	0.188	Nil	Nil	0.188	0.259	LF
6663	10-13-76	69-15318	UH-1H	119th Av Co	0.105	0.170	0.031	Nil	0.201	0.306	RF
6664	10-13-76	70-15613	OH-58A	"B" Co, 82nd Av Bn	High Particulate Concentration. See Table 11					47.100	
6665	10-13-76	72-21194	OH-58A	"B" Co, 82nd Av Bn						4.770	
6666	10-13-76	70-15150	OH-58A	"B" Co, 82nd Av Bn						17.800	
6667	10-13-76	69-16096	OH-58A	"B" Co, 82nd Av Bn						31.300	
6668	10-13-76	67-18430	CH-54A	478 Av Bn	Nil	0.141	Nil	Nil	0.141	0.141	Fwd
6669	10-13-76	67-18430	CH-54A	478 Av Bn	0.121	0.209	0.108	Nil	0.416	0.537	Aft
6670	10-13-76	67-18420	CH-54A	478 Av Bn	0.078	0.113	Nil	Nil	0.113	0.191	Fwd
6671	10-13-76	67-18420	CH-54A	478 Av Bn	0.370	0.472	0.121	Nil	0.593	0.963	Aft
6672	10-13-76	67-18424	CH-54A	478 Av Bn	0.335	0.286	0.099	Nil	0.385	0.720	Fwd
6673	10-13-76	67-18424	CH-54A	478 Av Bn	0.123	0.118	Nil	Nil	0.118	0.241	Aft
					(30.0)	(4.0)			(8.0)	(42.0)	

Notes. Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-E-8593B fluids.

[b] Calculated as Fe_2O_3, Al_2O_3 + CaO.

[a] All particulate matter less than 10 μm.

[c] Total Non-Ferrous Oxides = SiO_2 + Al_2O_3 + CaO.

[d] Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).

TABLE 11. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XV

Sample no.	Aircraft (unit)	Compound class	Estimated particulate concentration, g/1000 gal								
			≥1000 μm	500-100 μm	300-500 μm	102-300 μm	52-102 μm	26-52 μm	8-26 μm	0.45-8 μm	Total
6664	OH-58A,70-15613 ("B" Co 82nd Av Bn)	Iron oxides[a]	Nil	0.50	0.48	0.63	0.08	0.22	0.12	Nil	2.0
		Quartz[b]	0.098	4.35	6.90	25.56	0.70	0.56	0.53	0.10	38.8
		Calcium silicates	Nil	1.20	1.30	3.82	Nil	Nil	Nil	Nil	6.3
		Zinc compounds[c]	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6665	OH-58A,72-21194 ("B" Co 82nd Av Bn)	Iron oxides[a]							0.95		0.95
		Quartz[b]							3.82		3.82
		Calcium silicates							Nil		Nil
		Zinc compounds[c]							Nil		Nil
6666	OH-58A,70-15150 ("B" Co 82nd Av Bn)	Iron oxides[a]	0.74	0.15	0.26	0.51	0.46	0.32	0.16	Nil	2.6
		Quartz[b]	0.55	1.39	1.81	4.98	2.80	0.73	0.74	0.05	13.1
		Calcium silicates	0.16	0.12	0.15	0.97	0.60	Nil	0.14	Nil	2.1
		Zinc compounds[c]	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6667	OH-58A,69-16096 ("B" Co 82nd Av Bn)	Iron oxides[a]	Nil	0.21	0.20	1.62	0.91	0.32	0.25	Nil	3.5
		Quartz[b]	Nil	0.52	1.40	13.44	3.96	1.04	1.24	0.07	21.7
		Calcium silicates	Nil	0.45	Nil	3.44	1.11	0.16	0.98	Nil	6.1
		Zinc compounds[c]	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

[a] As Fe_2O_3.
[b] As SiO_2 (α-Quartz).
[c] ZnO and basic zinc carbonates, nonabrasive to steel.

TABLE 12. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR GALLANT CREW

Sample No	Date	Aircraft reg no	Aircraft type	Unit	Particulate Concentration, g/1000 gal:[a]						Sump
					Fe[b]	Si[b]	Al[b]	Ca[b]	Total Non-Ferrous Oxides[c]	Total Particulate Contaminants	
6878	3-28-77		Bladder No 1	13th COSCOM	0.077	0.625	Nil[d]	0.039	0.664	0.741	---
6879	3-28-77		Bladder No 2	13th COSCOM	0.058	Nil	Nil	Nil	Nil	0.058	---
6880	3-28-77	---	Bladder No 4	13th COSCOM	0.077	Nil	Nil	Nil	Nil	0.077	---
6881	3-28-77		Bladder No 6	13th COSCOM	Nil	Nil	Nil	Nil	Nil	Nil	---
6882	3-28-77		Bladder No 3	13th COSCOM	Nil	Nil	Nil	Nil	Nil	Nil	---
6883	3-28-77	70-16211	UH-1H	HHC Troop 4-9 Cav	0.103	0.460	Nil	Nil	0.460	0.563	RI
6884	3-28-77	70-16211	UH-1H	HHC Troop 4-9 Cav	0.077	0.313	Nil	Nil	0.313	0.390	LI
6885	3-28-77	71-20554	OH-58A	"A" Troop 7/17 Cav	0.198	1.063	0.388	0.221	1.670	1.868	---
6886	3-28-77	71-20224	UH-1H	HHC Troop 7/17 Cav	0.058	0.258	Nil	Nil	0.258	0.316	LI
6887	3-28-77	71-20224	UH-1H	HHC Troop 7/17 Cav	Nil	0.263	Nil	Nil	0.263	0.263	RI
6888	3-28-77	69-15010	UH-1H	HHC Troop 7/17 Cav	Nil	Nil	Nil	Nil	Nil	Nil	LI
6889	3-28-77	69-15010	UH-1H	HHC Troop 7/17 Cav	0.065	Nil	Nil	Nil	Nil	0.065	RI
6890	3-28-77	71-20223	UH-1H	HHC Troop 7/17 Cav	0.122	0.608	0.188	0.117	1.913	2.035	LI
6891	3-28-77	71-20223	UH-1H	HHC Troop 7/17 Cav	0.152	0.791	0.223	0.242	1.256	1.256	RI
6892	3-28-77	70-15371	OH-58A	3rd Bde Tst Cav	0.105	0.839	0.149	0.109	1.096	1.201	---
6893	3-28-77	70-15010	CH-47C	"D" Co, 34th Spt 6ACCB	0.517	1.333	0.929	0.114	2.376	2.893	LI
6894	3-28-77	70-15010	CH-47C	"D" Co, 34th Spt 6ACCB	0.084	0.278	Nil	Nil	0.278	0.362	RI
6895	3-28-77	70-15008	CH-47C	"D" Co, 34th Spt 6ACCB	High Particulate Concentration (see Table 13)					11.780	LI
6896	3-28-77	70-15008	CH-47C	"D" Co, 34th Spt 6ACCB	0.558	1.665	Nil	Nil	1.665	2.223	RI
6897	3-28-77	70-15027	CH-47C	"D" Co, 34th Spt 6ACCB	1.007	5.490	2.242	0.073	7.805	8.812	LI
6898	3-28-77	70-15027	CH-47C	"D" Co, 34th Spt 6ACCB	1.465	8.754	3.738	0.887	13.378	14.843	RI
6899	3-28-77	70-15025	CH-47C	"D" Co, 34th Spt 6ACCB	0.107	Nil	Nil	Nil	Nil	0.107	LI
6900	3-28-77	70-15025	CH-47C	"D" Co, 34th Spt 6ACCB	0.104	0.262	Nil	0.297	0.560	0.664	LM
6901	3-28-77	70-15025	CH-47C	"D" Co, 34th Spt 6ACCB	0.638	5.460	1.614	2.741	9.814	10.452	RR
6902	3-28-77	70-15025	CH-47C	"D" Co, 34th Spt 6ACCB	0.354	1.706	0.515	1.044	3.265	3.619	RM
6903	3-29-77	66-00888	UH-1H	528th Trans, 13th COSCOM	0.083	Nil	Nil	Nil	Nil	0.083	LI
6904	3-29-77	66-00888	UH-1H	528th Trans, 13th COSCOM	0.123	0.111	Nil	Nil	0.111	0.234	RI
6905	3-29-77	70-16265	UH-1H	162 Av Co (AH)	0.067	Nil	Nil	Nil	Nil	0.067	LI
6906	3-29-77	70-16265	UH-1H	162 Av Co (AH)	0.090	Nil	Nil	Nil	Nil	0.090	RI
6907	3-29-77	68-16614	UH-1H	162 Av Co (AH)	0.269	0.646	Nil	0.546	1.192	1.461	LI
6908	3-29-77	68-16614	UH-1H	162 Av Co (AH)	0.127	0.246	Nil	Nil	0.246	0.373	RI
6909	3-29-77	68-16627	UH-1H	162 Av Co (AH)	0.082	Nil	Nil	Nil	Nil	0.082	LI
6910	3-29-77	68-16627	UH-1H	162 Av Co (AH)	0.087	Nil	Nil	Nil	Nil	0.087	RI
6911	3-29-77		Bladder	108th QM	0.063	Nil	Nil	Nil	Nil	0.063	---
6912	3-29-77	PSL 132	Tank Truck	108th QM	0.093	Nil	Nil	Nil	Nil	0.093	Nozzle Compartment
6913	3-29-77	PSL 132	Tank Truck	108th QM	0.067	Nil	Nil	Nil	Nil	0.067	
6914	3-29-77	70-15019	CH-47C	"D" Co, 34th Spt 6 ACCB	High Particulate Concentration (see Table 13)					158.920	RI
6915	3-29-77	70-15019	CH-47C	"D" Co, 34th Spt 6 ACCB	0.522	0.511	0.329	0.163	1.003	1.325	RR
6916	3-29-77	70-15019	CH-47C	"D" Co, 34th Spt 6 ACCB	1.663	10.828	3.726	7.376	21.930	23.593	LI
6917	3-29-77	70-15019	CH-47C	"D" Co, 34th Spt 6 ACCB	0.189	0.233	1.223	0.521	1.977	2.166	LR
					(30.0)	(4.0)			(8.0)	(42.0)	

Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AVCAT-85930 fluids.

[b] Calculated as Fe_2O_3, SiO_2, Al_2O_3, + CaO

[a] All particulate matter less than 10 µm

[c] Total Non-Ferrous Oxides = SiO_2 + Al_2O_3 + CaO

[d] Nil: Below level limit + resolution by X-Ray Fluorescence (< 0.001 g/1000 gal)

TABLE 13. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR GALLANT CREW

Sample no.	Aircraft (unit)	Compound class	Estimated particulate concentration, g/1000 gal							Total
			≥1000 μm	500-1000 μm	300-500 μm	102-300 μm	52-102 μm	26-52 μm	8-26 μm	0.45-8 μm	
6914	CH-47C, 70-15019[a] (7th Co, 34th Spt, 6AACB)	Iron oxides[b]	3.15	1.88	2.41	10.90	2.46	0.80	0.84	Nil	22.44
		Quartz[c]	0.84	4.24	5.73	47.26	11.06	4.93	6.21	Nil	80.27
		Calcium silicates	0.25	4.23	3.88	31.72	7.99	3.37	4.77	Nil	56.21
		Zinc compounds[d]	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6895	CH-47C, 70-15008[e] (7th Co, 34th Spt, 6AACB)	Iron oxides[b]	Nil	Nil	0.34	0.80	0.10	0.03	0.36	Nil	1.63
		Quartz[c]	Nil	Nil	0.32	3.17	0.62	0.27	1.32	Nil	5.70
		Calcium silicates	Nil	Nil	0.10	1.80	0.07	Nil	2.48	Nil	4.45
		Zinc compounds[d]	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

[a] Left front drain.
[b] As Fe_2O_3.
[c] As SiO_2 (α-quartz).
[d] ZnO and basic zinc carbonates, nonabrasive to steel.
[e] Right front drain.

V. DISCUSSION

From the preceding data, it can be seen that (a) the vast majority of all aircraft sump drain samples contain nowhere near the concentration of the particulates specified by AV-E-8593B, but (b) an unexpectedly high number of aircraft samples (roughly 7 percent) plus numerous points in the refueling systems showed concentrations far exceeding those specified for this package. The fact that drain samples taken from operational Army aircraft contained concentrations of the same order as a test contaminant package criticized for its severity must be placed into proper perspective. These samples were (a) taken from the lowest point in the aircraft fuel systems, (b) upstream of on-board aircraft fuel filtration elements, (c) cumulative in the sense that most residual particulate matter will settle to the drain area over a period of time, and (d) calculated as oxides of the elements identified (Fe_2O_3, SiO_2, Al_2O_3, CaO) as opposed to costly quantitative analysis required for identification of clay-like compounds.

For the above reasons, the data as presented represent a *worst possible case* with respect to comparison to specification values. It can be properly argued as to whether any of the contaminants as identified by sump drain would pass through on-board filtration systems and, even if this occurred, would result in significant, cumulative damage to the powerplant system. It must be presumed that such abrasive contaminants as quartz (SiO_2) could cause significant fuel pump wear, malfunction of close-tolerance servo-valves, and degradation/failure of miniature bearings. The effect of less abrasive calcium aluminum silicates (clays) must be assumed to be minor with respect to wear and abrasion, but would contribute to degradation of precision components. Iron oxides are relatively less abrasive than quartz but could contribute to wear and system malfunction.

Probably the most important fact uncovered by this investigation is that significant quantities of the exact elements and compounds as specified in AV-E-8593B were, in fact, found in on-board aircraft fuel systems even though this fuel had been subjected to the extensive upstream filtration prescribed for Army aviation fuel supply.

VI. ARIZONA ROAD DUST COMPOSITION

Coarse Arizona Road Dust (A.C. Spark Plug Co. Part No. 1543637) is a component in the fuel contamination package used to meet AV-E-8593B specifications (see Table 1). This dust has traditionally been reported to be composed of:

$4 \pm 1\%$ Fe_2O_3
$68 \pm 1\%$ SiO_2
$16 \pm 1\%$ Al_2O_3
$3 \pm 1\%$ CaO
$1 \pm 1\%$ MgO

Since several field samples had been found to contain both the above compounds and more complex clay-like materials, a separate study on Arizona Road Dust composition was undertaken. Different batches of AC dust were obtained and analyzed by X-ray fluorescence spectroscopy. The results obtained are compiled in Table 14.

One batch (Lot No. C-306) was separated by particle size, and each particle range analyzed by X-ray fluorescence for elemental content. These results are shown in Table 15.

X-ray diffraction data for mineralogical species was also obtained on Lot C-306. The diffraction data and the X-ray fluorescence data permitted the calculation of minerological composition. The results showed the test dust to be composed of:

72% $Ca(Mg)_{.23}$ $Na_{.77}$ $AlSi_{2.77}O_8$ (a plagioclase feldspar),
20% SiO_2 (α-quartz), and
8% Fe_3O_4 (magnetite).

TABLE 14. X-RAY FLUORESCENCE ANALYSIS OF VARIOUS LOTS OF AC TEST DUST

Lot No.	% Al	% Si	% Ca	% Ti	% Fe	Remarks
F-049	6.8	26.8	0.8	0.3	2.0	F indicates "fine"
F-138	7.7	30.1	0.8	0.2	2.1	
C-306	6.9	29.4	1.2	0.3	2.2	C indicates "coarse"
C-349	7.8	32.0	1.1	0.3	2.2	
C-362	6.9	28.0	1.1	0.3	2.2	
C-364	6.8	27.9	1.0	0.3	2.2	
C-387	6.8	28.4	0.8	0.2	1.8	
Mean	7.1	28.9	1.0	0.3	2.1	
As Oxides	13.4	61.8	1.4	0.4	3.0	
Reported values	16 ± 1	68 ± 1	3 ± 1	Not reported	4 ± 1	

TABLE 15. X-RAY ANALYSIS OF VARIOUS SIZED PARTICLES OF AC TEST DUST, LOT NO. C-306

Particle Size, μm	% Sample	% Al	% Si	% Ca	% Ti	% Fe	Remarks
>500	0.3						Insufficient sample
500-300	0.3						Insufficient sample
300-102	18.0	4.4	18.8	1.0	0.3	1.8	
102-53	40.4	5.2	21.0	0.3	-	1.6	
52-26	26.0	5.7	25.6	1.1	0.2	1.5	
<26	15.0	3.8	17.9	0.2	0.2	1.1	
	100.0						

2300X

FIGURE 7. SCANNING ELECTRON PHOTOMICROGRAPH OF 26- TO 52-μm PARTICLES OF A.C. TEST DUST (LOT C-306, TABLE 15)

To verify this compositional conclusion, a sample of the 26- to 52-μm sized test dust from Lot No. C-306 was examined under a scanning electron microscope (SEM). The total image is shown in Figure 7. The crystallographic form of the almost rectangular particle in the upper right quadrant appears to be different from that of the other large particles. In the SEM process, X-rays are emitted from all areas of the sample. These X-rays may be analyzed for energy distribution, and the sample can be mapped for elemental content. Such element maps were obtained for silicon and aluminum. The map for silicon indicated that all particles contained silicon. However, the map for aluminum showed that the previously mentioned particle in the upper right quadrant contained far greater amounts of aluminum than do the other particles. This indicates that this particle contains both silicon and aluminum and is chemically different from the other particles in Figure 7 which are quartz. This supports the X-ray diffraction data which indicate a mixture of mineral types present in the test dust.

The conclusions drawn from this study are that:

(1) the A.C. Test Dust is relatively uniform in composition over the various particle size ranges examined, and

(2) that A.C. Test Dust is not a mixture of metal oxides as commonly believed but is a mixture of three mineral species.

These mineral species (quartz, plagioclase, and magnetite) have significantly different properties both from one another and from the properties of the metal oxides typically listed. These mineral species are, in two out of three cases (quartz and magnetite), redundant with other components of the fuel contaminant package for AV-E-8593B engine component qualification testing. The plagioclase component is soft and would not abrade the ferrous metals in a fuel system as would quartz. The plagioclase thus contributes no severity to the test. As a result, the A.C. Test Dust really contributes nothing to the test that the other components of the test package do not already accomplish.

It is interesting to note that X-ray diffraction studies of several selected samples obtained in the field from fuel tanks showed the material to be similar in composition to the test package in that oxides of iron, quartz, and minerals in the plagioclase feldspar family were identified (for example,

see Tables 5 and 6). *Therefore, the test package does indeed resemble the types of contaminants found in the field but is redundant in some of its components and contains some material which would not stress a candidate gas turbine engine component.*

VII. CONCLUSIONS

Specific conclusions which can be derived from this program are:

(1) The same contaminants as specified in AV-E-8593B are encountered in field Army aviation operations.

(2) These contaminants are encountered at levels approaching or exceeding AV-E-8593B in a disproportionately high incidence.

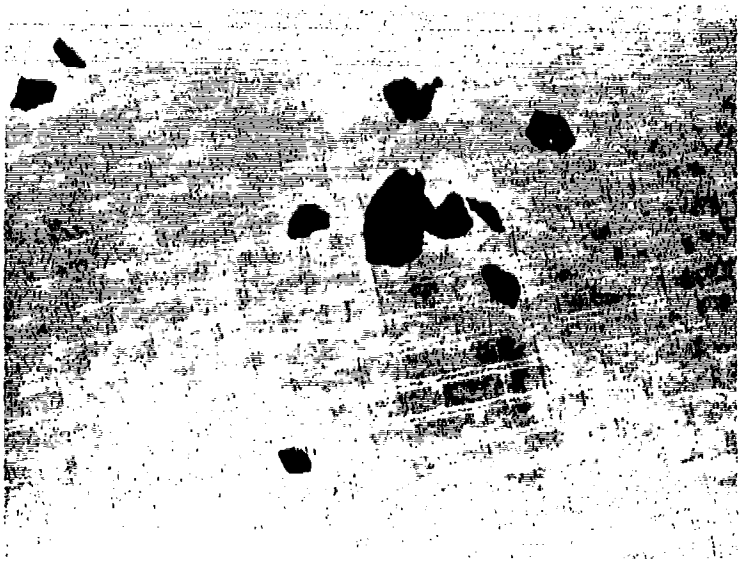
(3) For the above reasons, the contaminant package in AV-E-8593B is valid for the purpose of accelerated qualification testing of fuel system components.

It should be noted and emphasized that all the aircraft included in this program had been operating satisfactorily, probably due to on-board fuel filtration systems. The utilization of this contaminant package for test fluids in AV-E-8593B has undoubtedly benefitted Army aviation flight safety and maintenance.

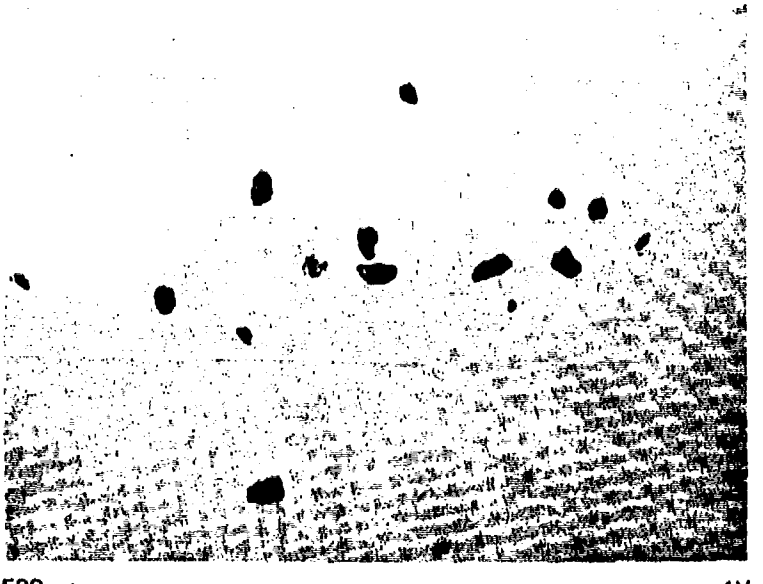
APPENDIX A
FILTRATION PHOTOMICROGRAPHS FOR NEW MEXICO ANG TRAINING OPERATION

APPENDIX A-1
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6466

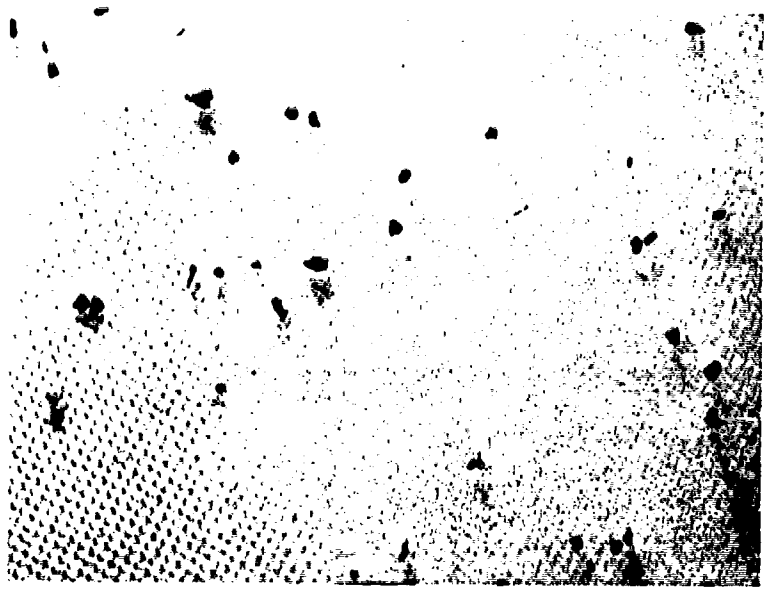
Biggs AAF Tank 3 Bottoms
(See Table 5)



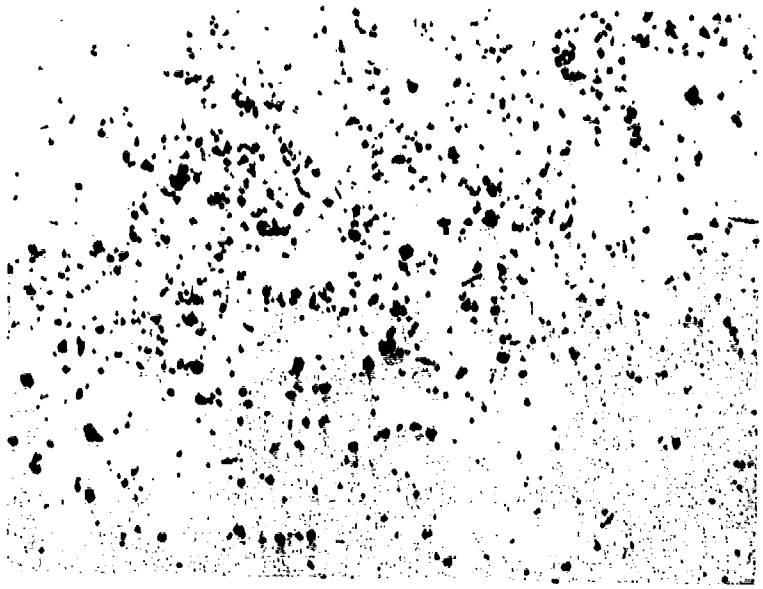
1000μm 4X



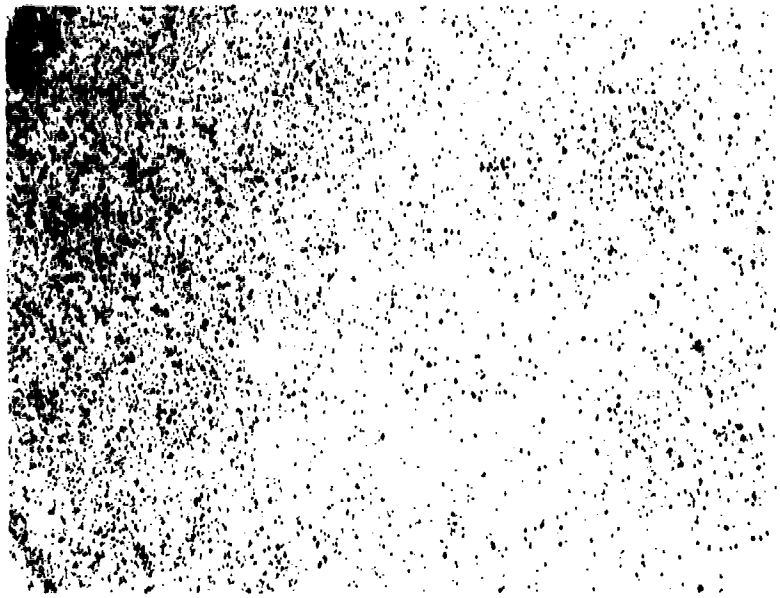
500μm 4X



300μm 4X



102μm 4X

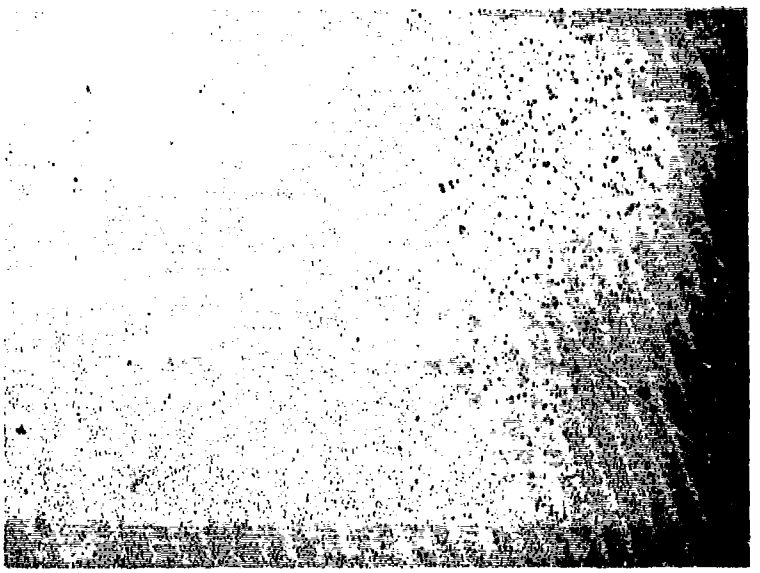


52μm 4X

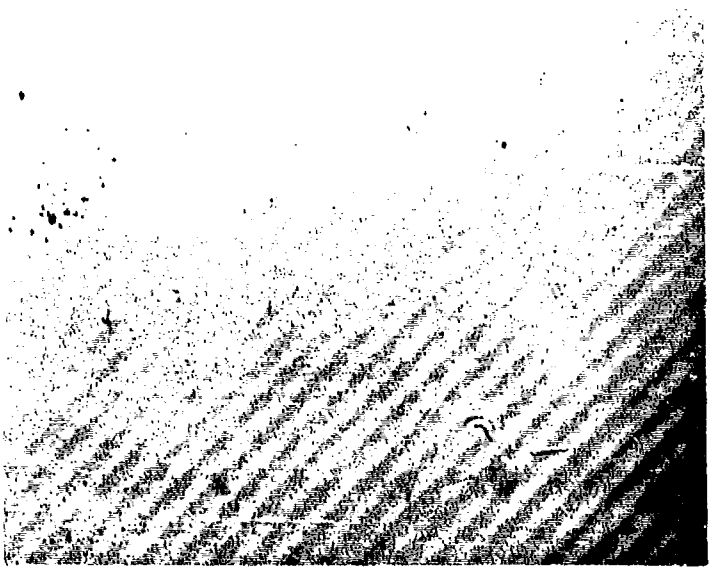
26μm 4X

8μm 4X

8μm 4X



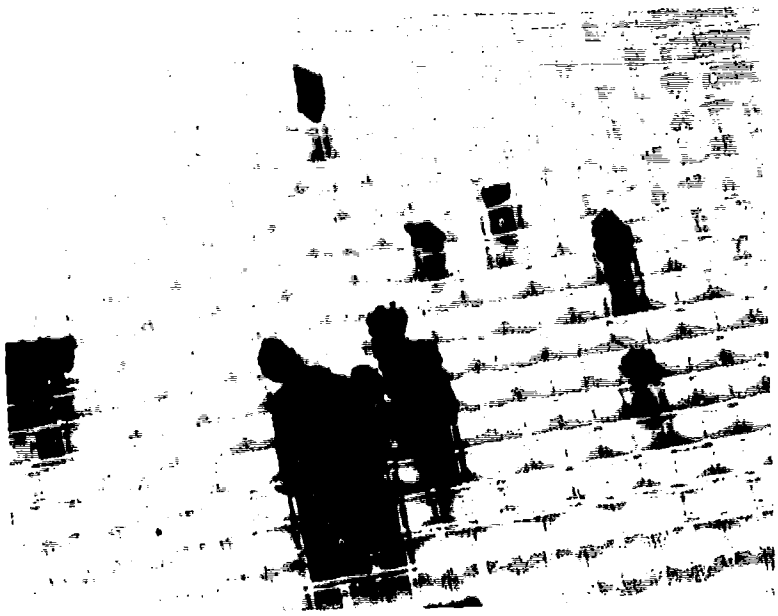
0.45μm 4X



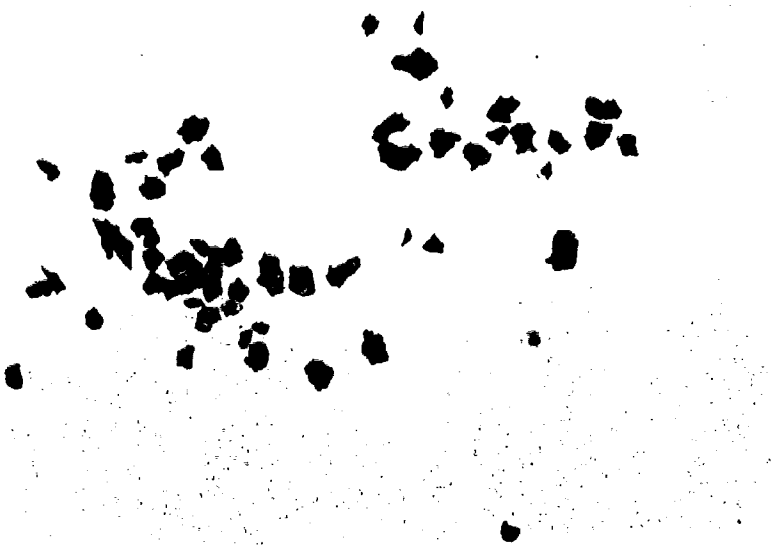
0.45μm 4X

APPENDIX A-2
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6476

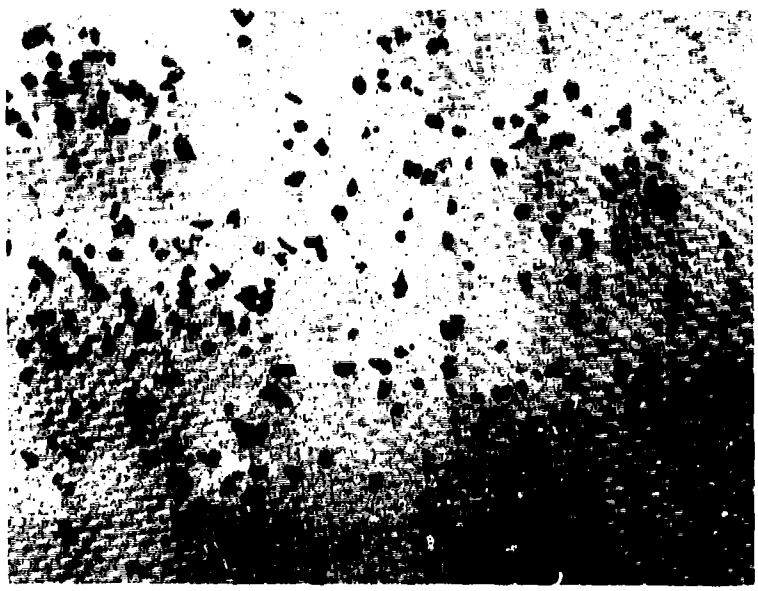
Biggs AAF Tank 5 Bottoms
(See Table 5)



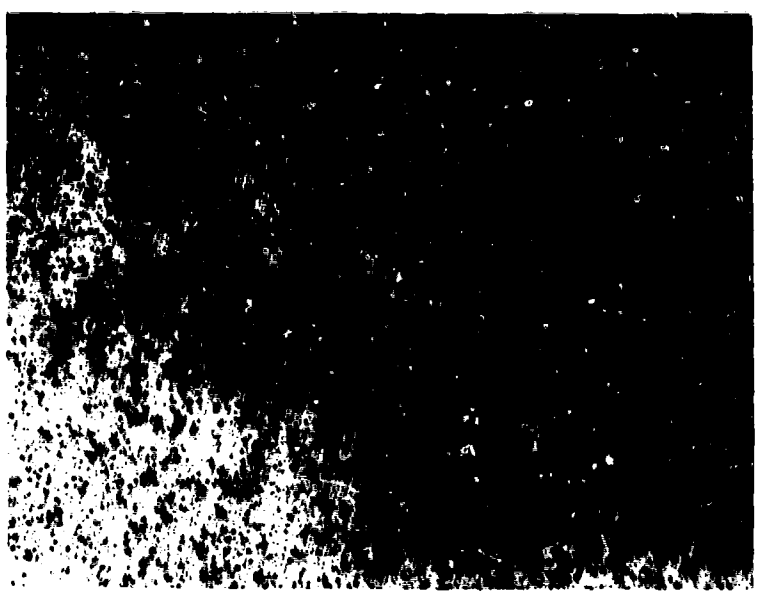
1000μm 4X



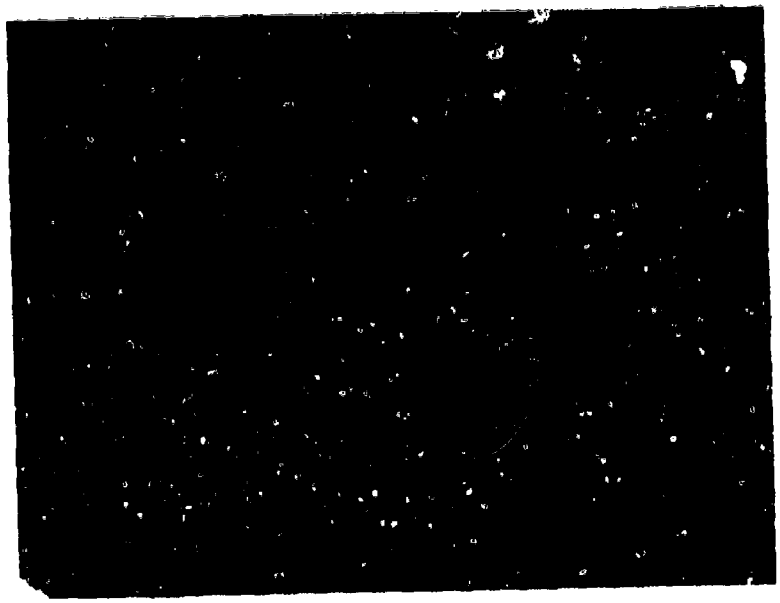
500μm 4X



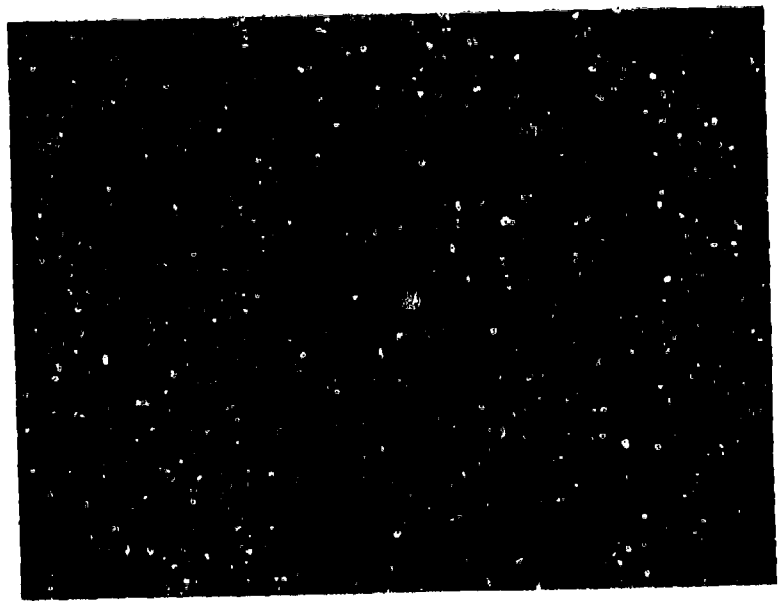
300μm 4X



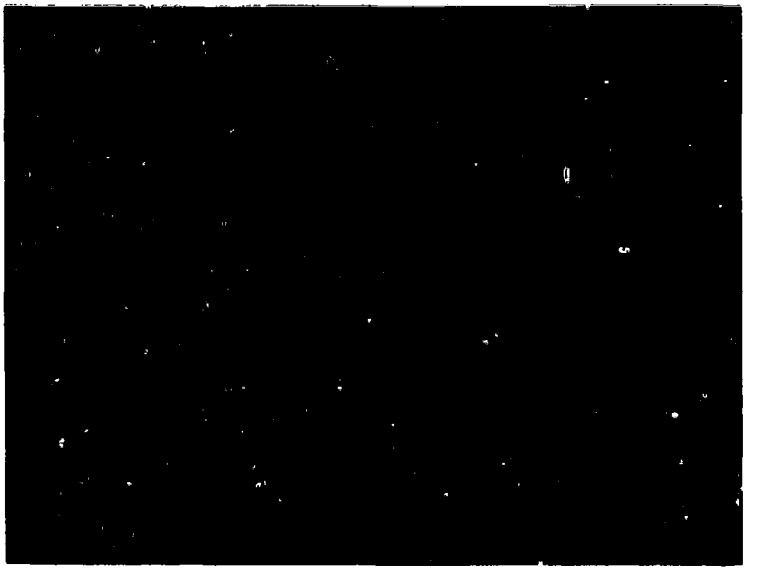
102μm 4X



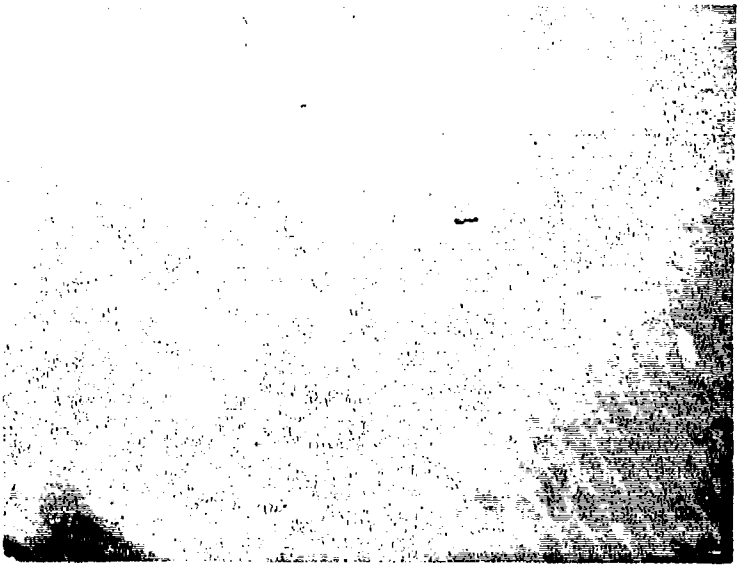
52μm 4X



26μm 4X



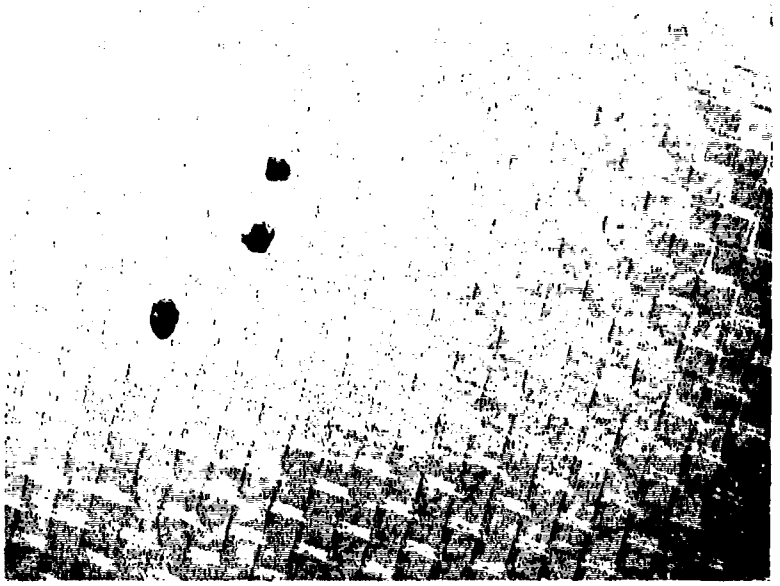
8μm 4X

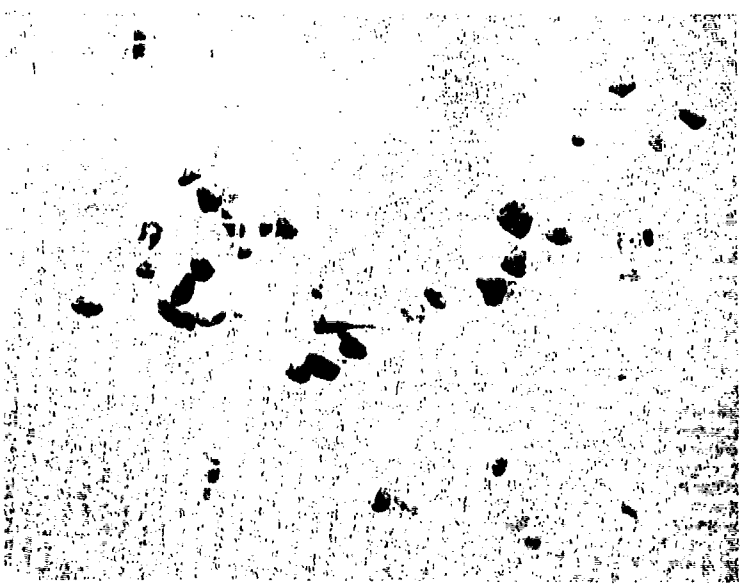


0.45μm 4X

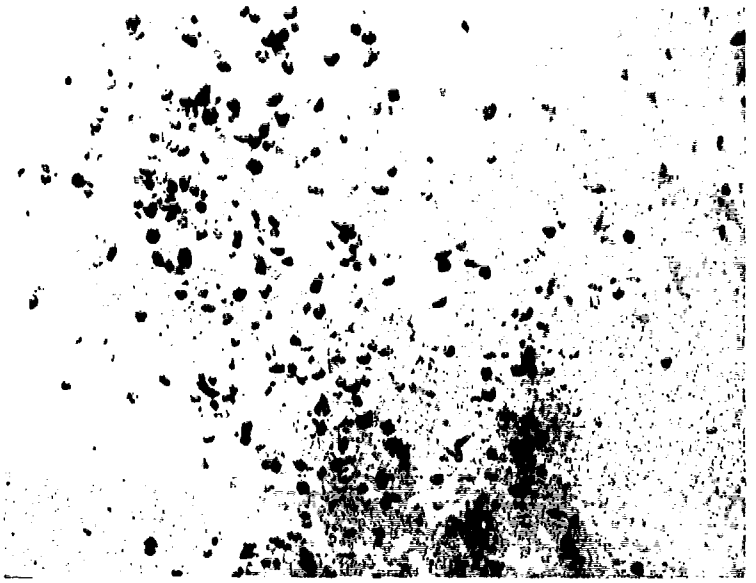
APPENDIX A-3
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6486

Biggs AAF Tanks 3/4 Nozzle (After Filter)
(See Table 5)

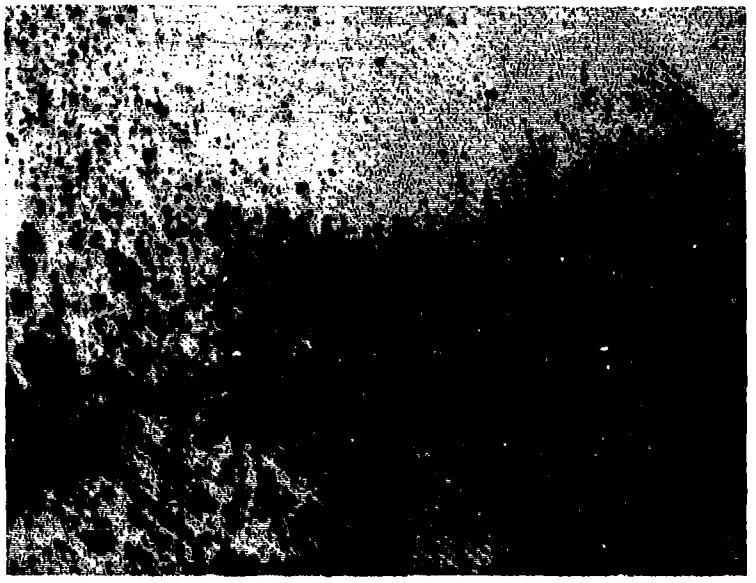




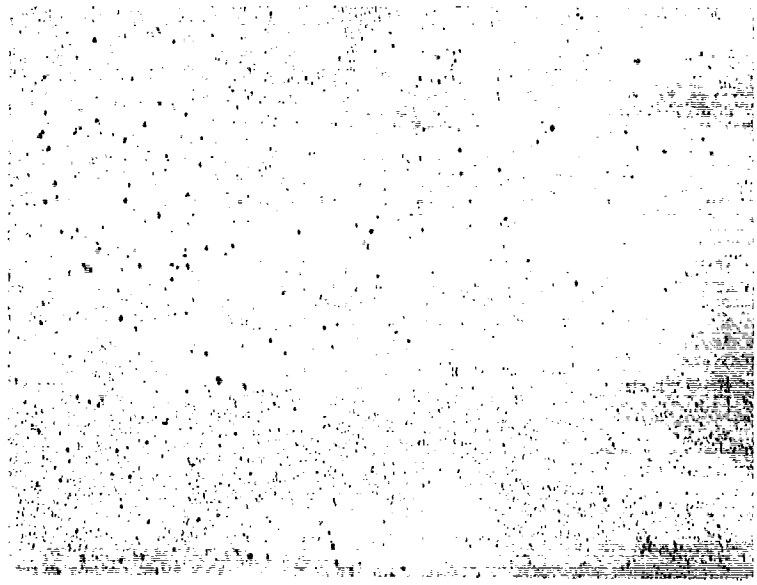
500μm 4X



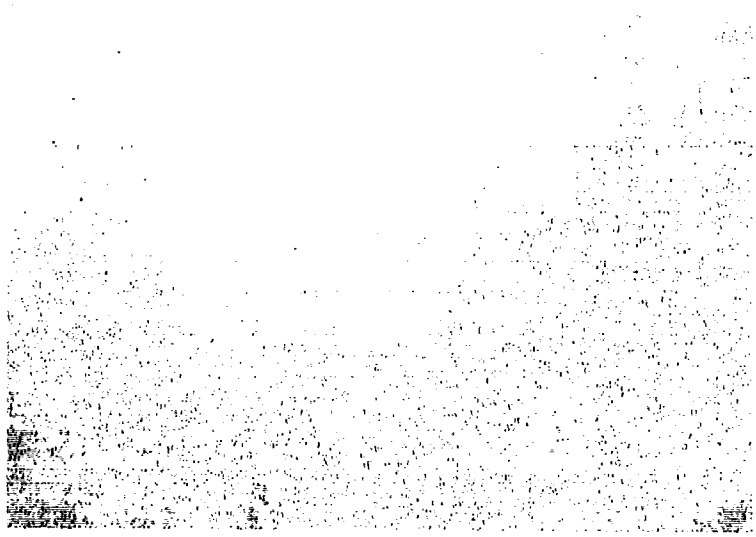
300μm 4X



102μm 4X



52μm 4X



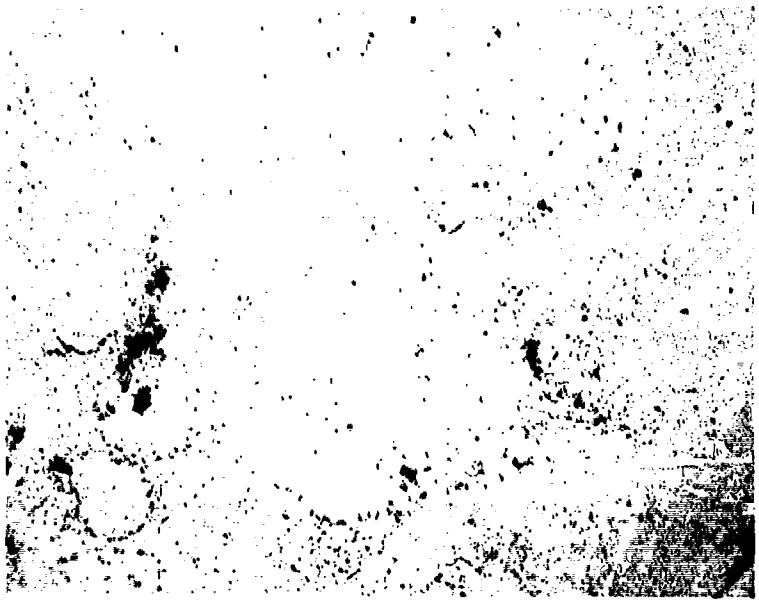
26μm 4X

8μm 4X

0.45μm 4X

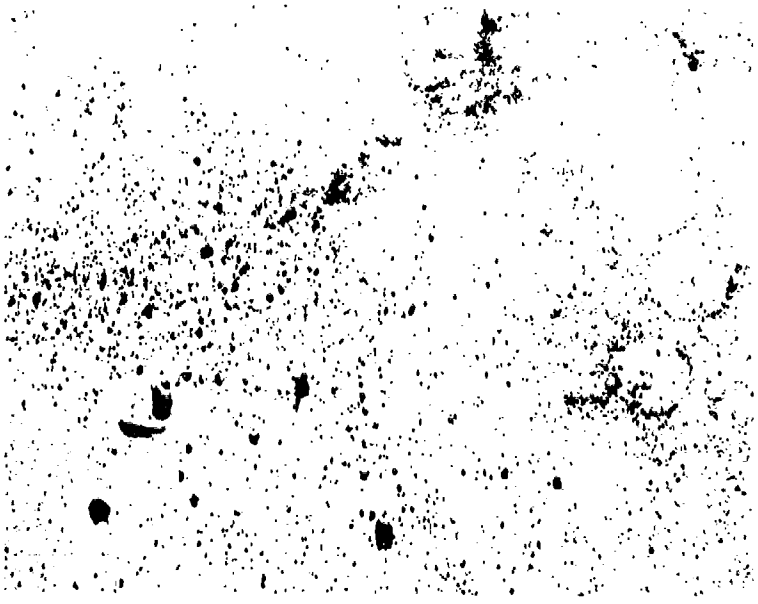
APPENDIX A-4
8-μm FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6471
(Center of Tank 4)
and
SAMPLE NO. 6481
(Center of Tank 6)

Biggs AAF
(See Table 5)



8μm 4X

SAMPLE 6471

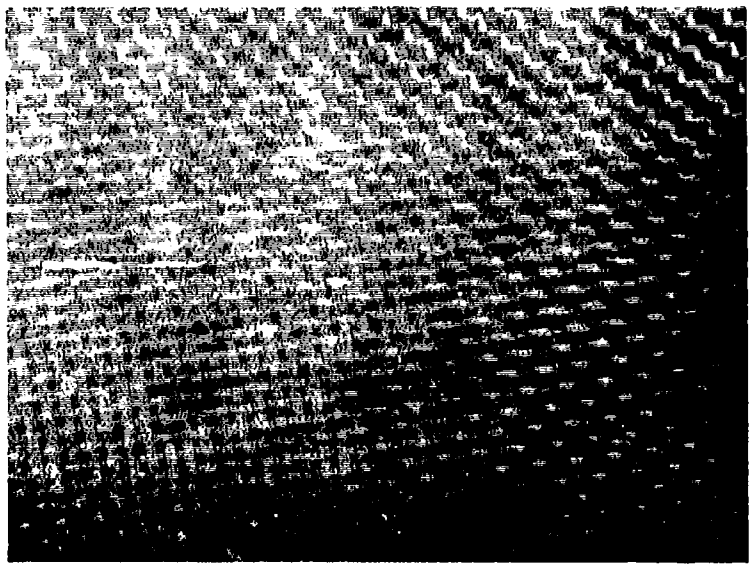


8μm 4X

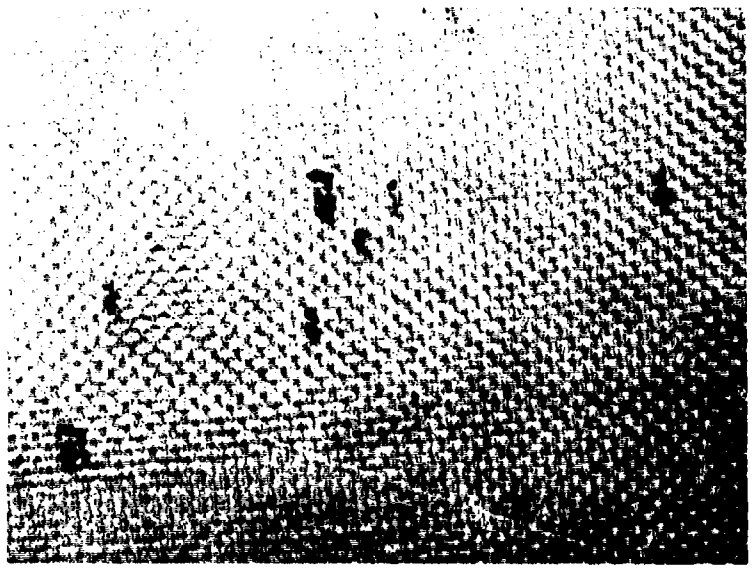
SAMPLE 6481

APPENDIX A-5
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6496

OH-58A, 71-20667
(See Table 6)



500μm 4X

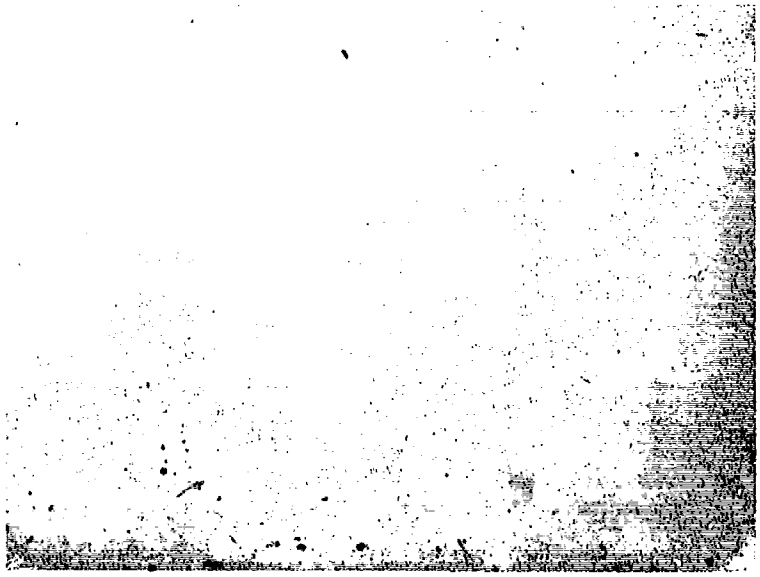


300μm 4X

102μm 4X

52μm 4X

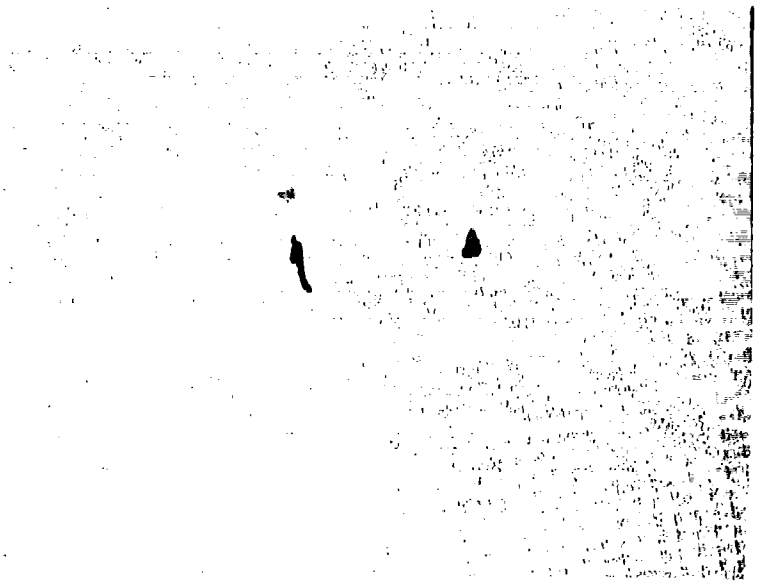
26μm 4X



8μm 4X

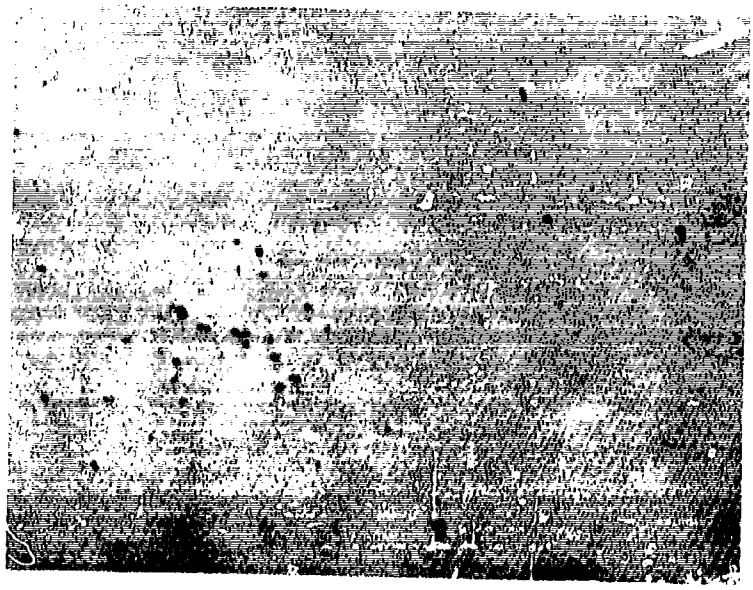
APPENDIX A-6
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6499

AH-1G, 70-15953
(See Table 6)

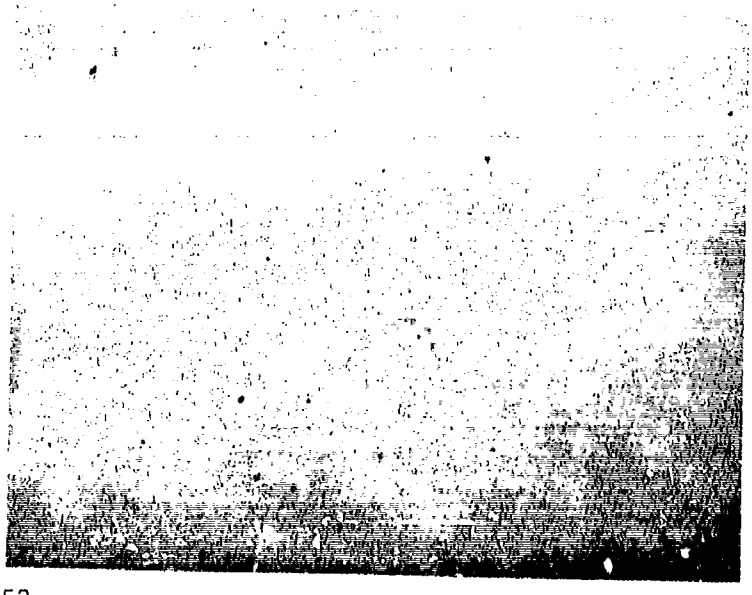


500μm 4X

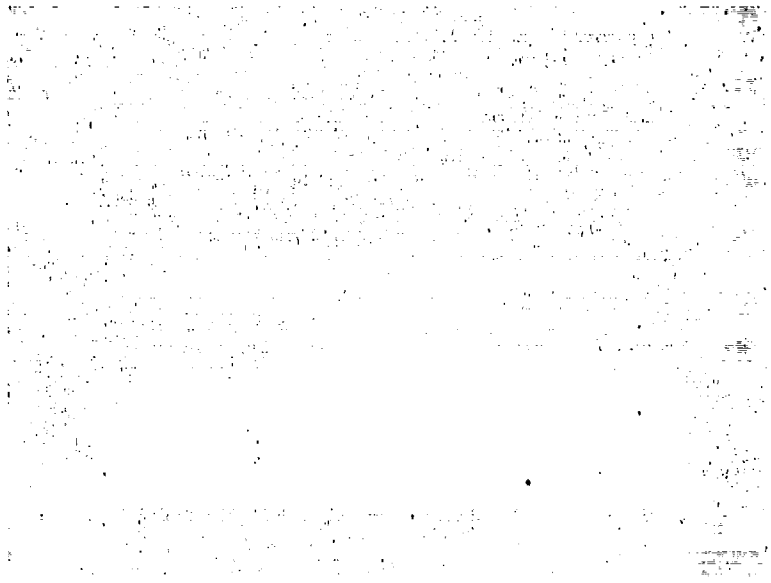
300μm 4X



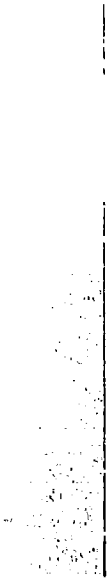
102μm 4X



52μm 4X



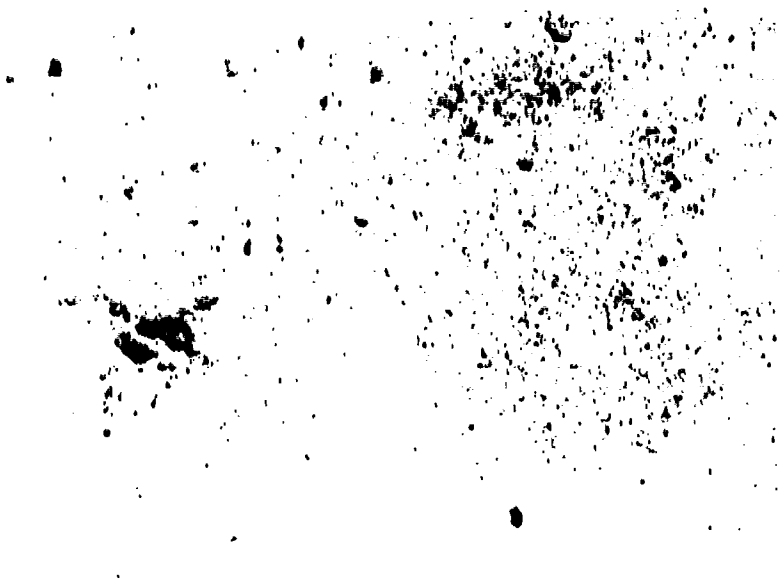
26μm 4X



8μm 4X

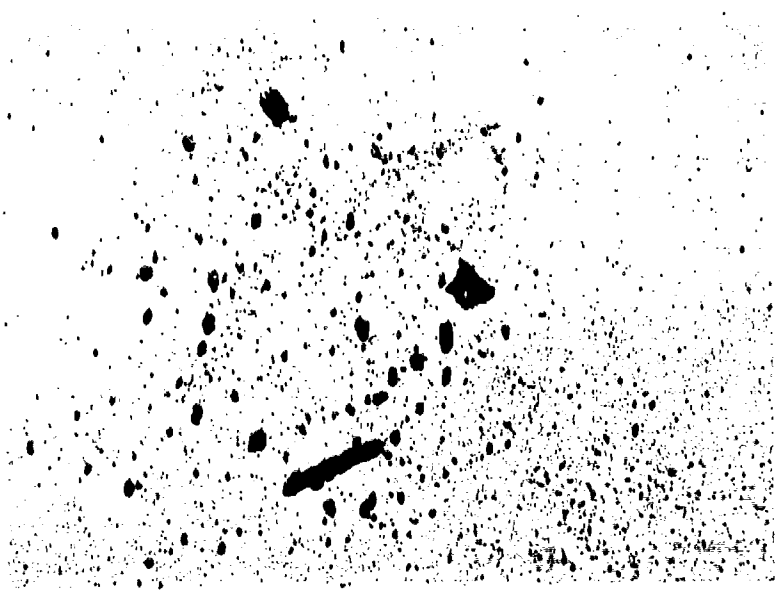
APPENDIX A-7
8-μm FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6487
(AH-1G, 71-20984 Aft Drain)
and
SAMPLE NO. 6492
(AH-1G, 71-20984 Front Drain)

Biggs AAF
(See Table 6)



8μm 4X

SAMPLE 6487



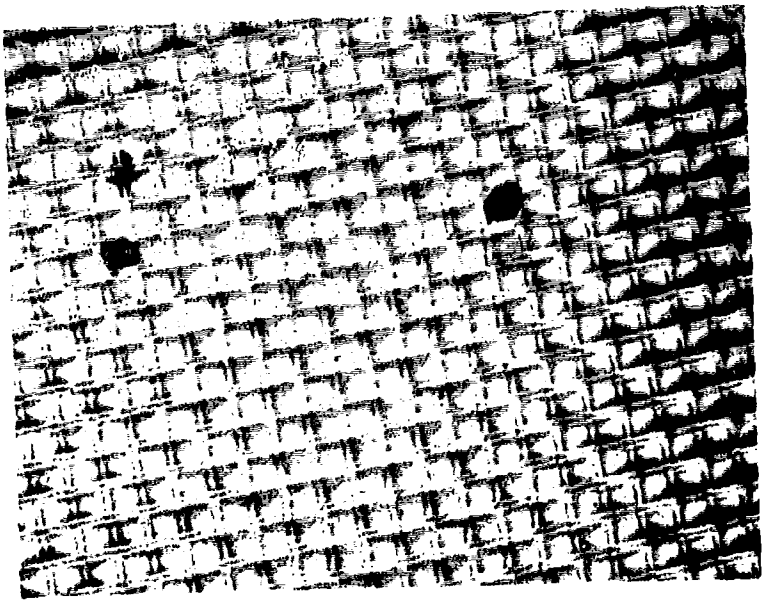
8μm 4X

SAMPLE 6492

APPENDIX B
FILTRATION PHOTOMICROGRAPHS FOR OPERATION REFORGER

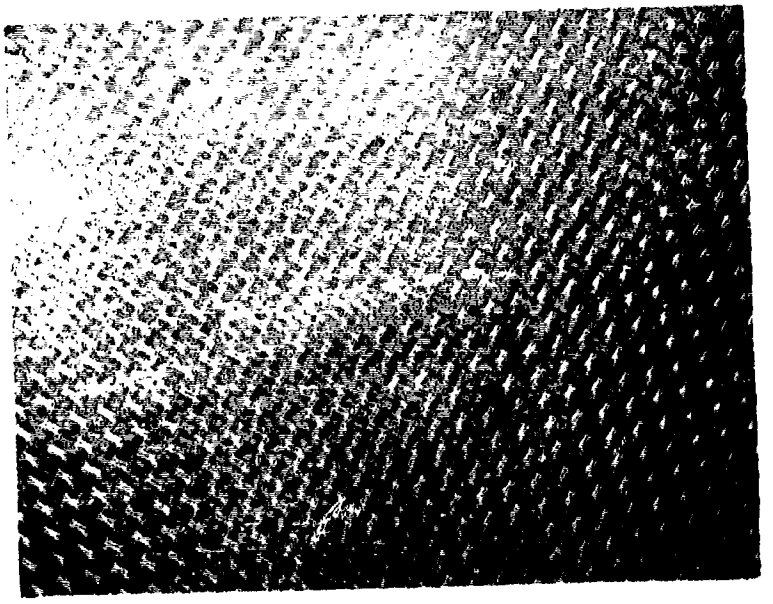
APPENDIX B-1
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6594

AH-1G, 70-16045 Front Drain
(See Table 9)



1000μm

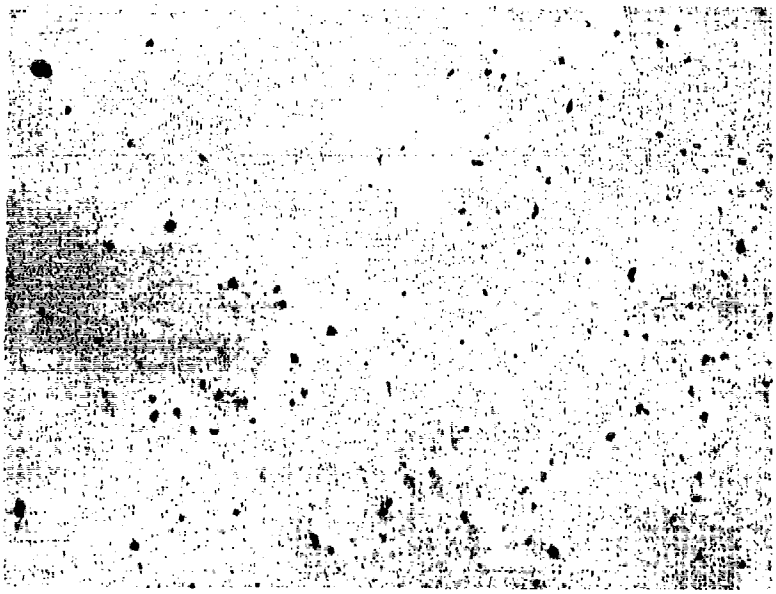
4X



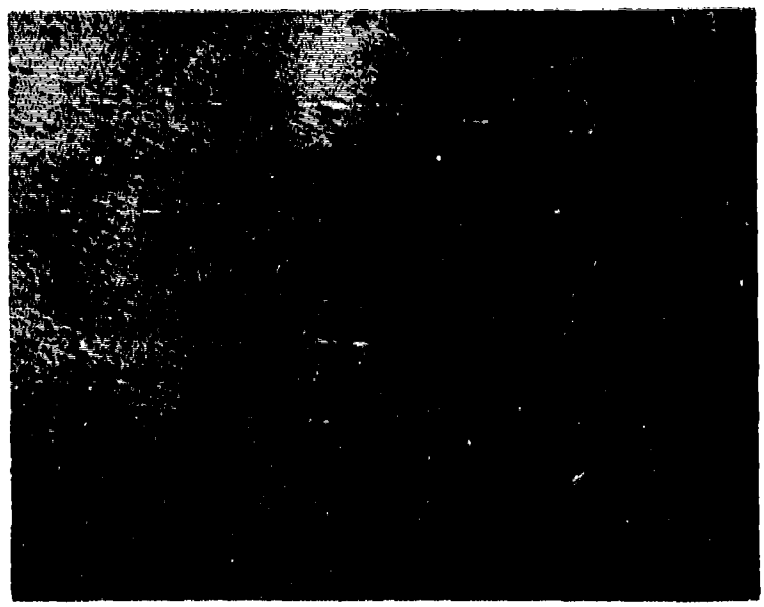
500μm

4X

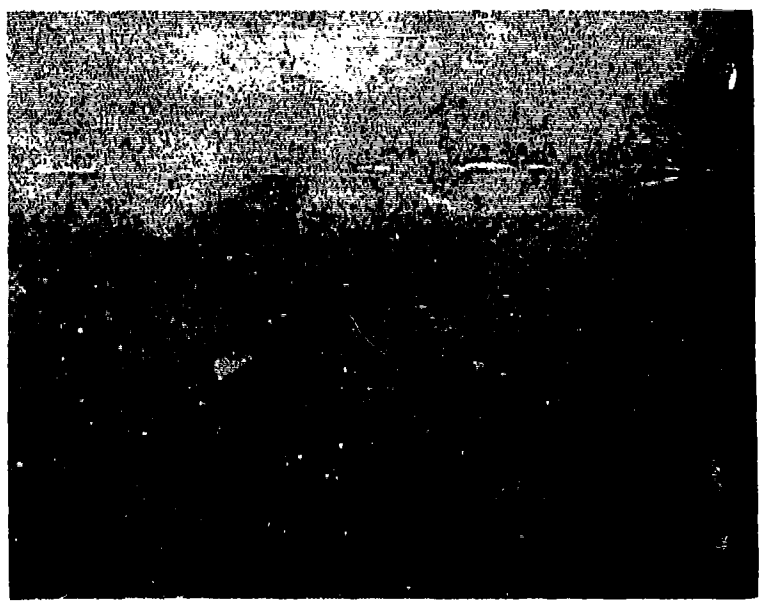
300μm 4X



102μm 4X

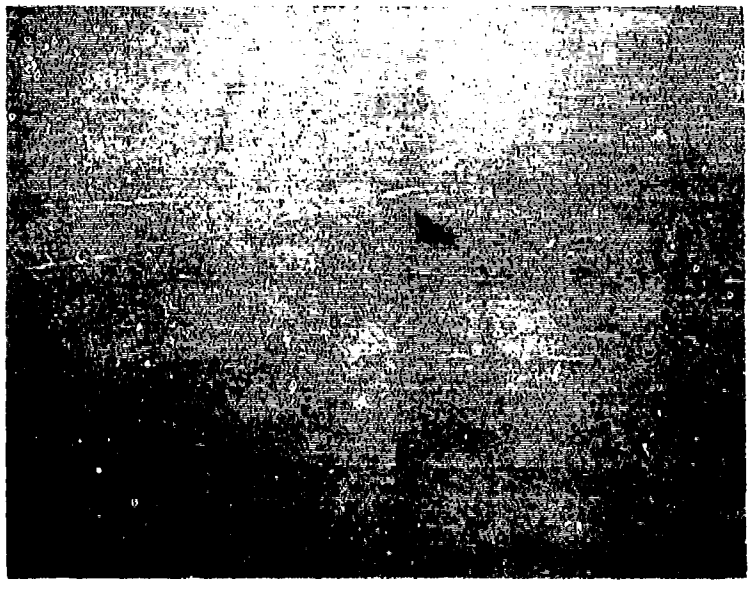


52μm 4X



26μm 4X

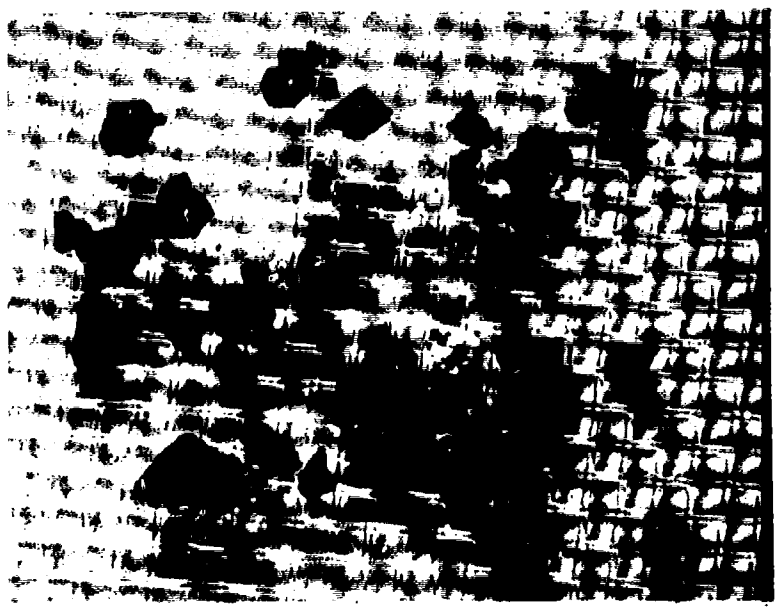
8μm 4X



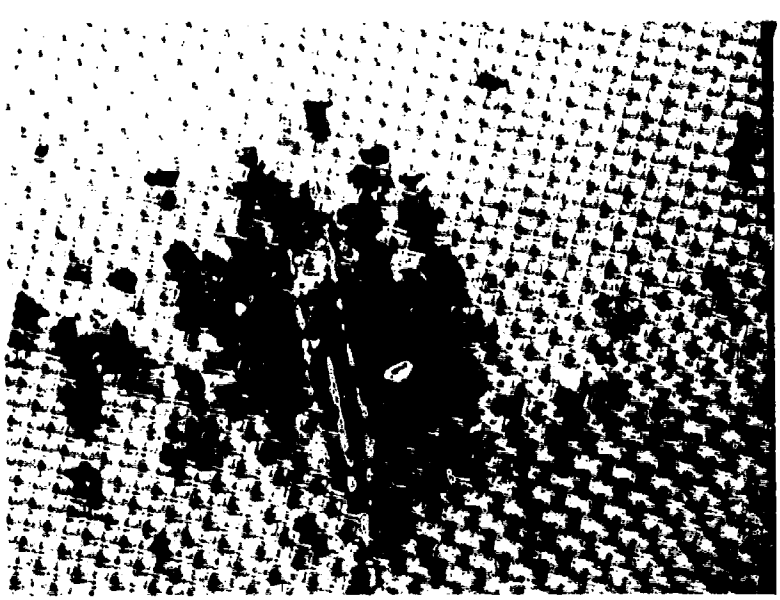
.45μm 4X

APPENDIX B-2
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6603

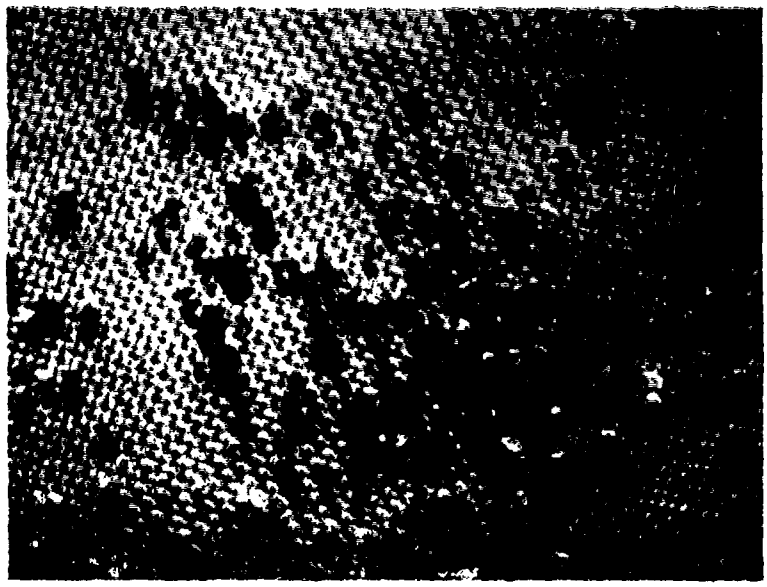
OH-58A, 71-20497
(See Table 9)



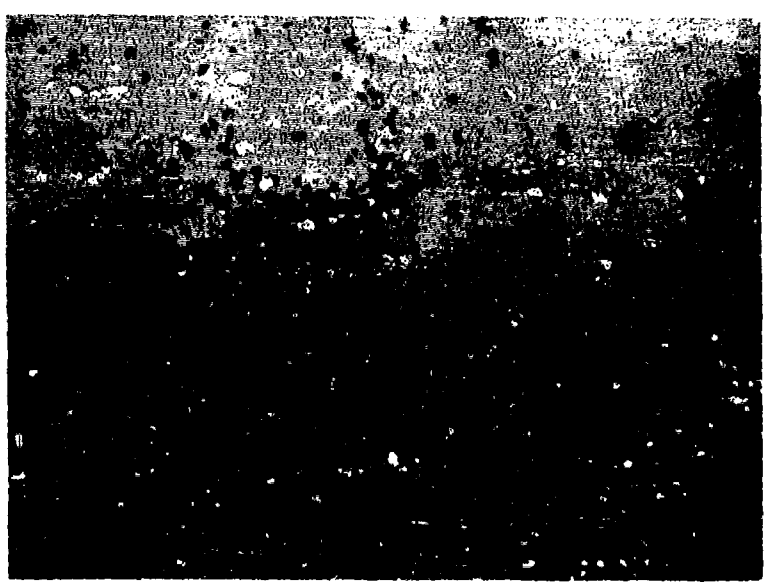
1000μm 4X



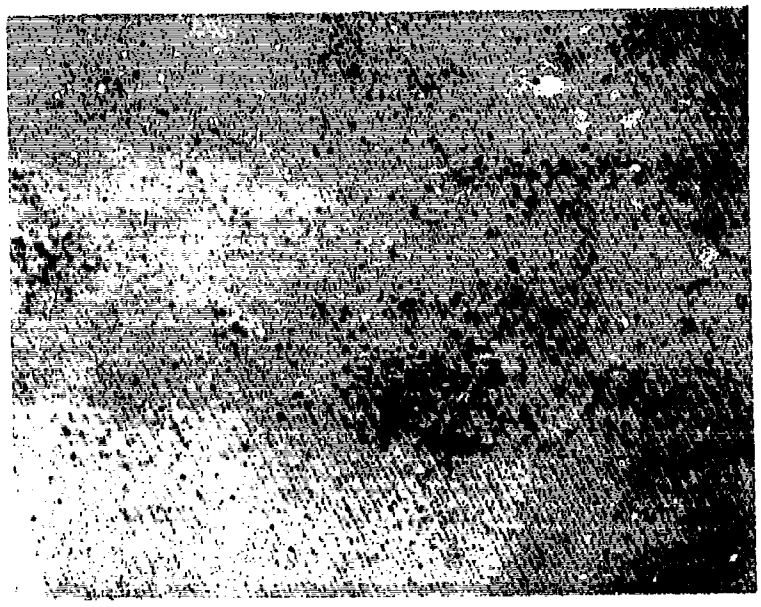
500μm 4X



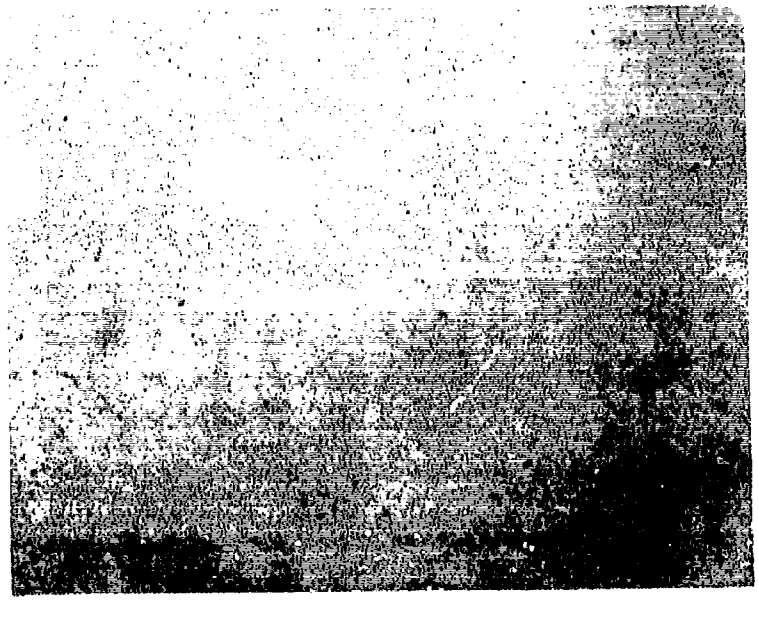
300μm 4X



102μm 4X

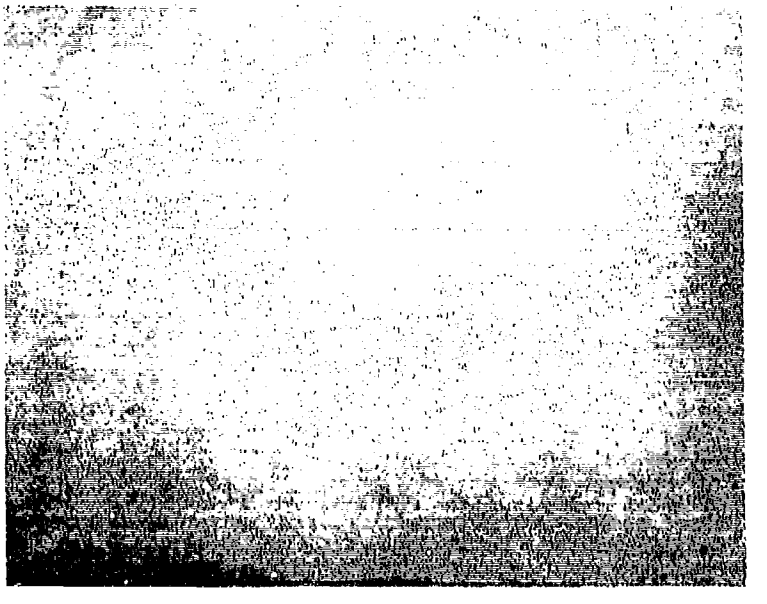


52μm 4X



26μm 4X

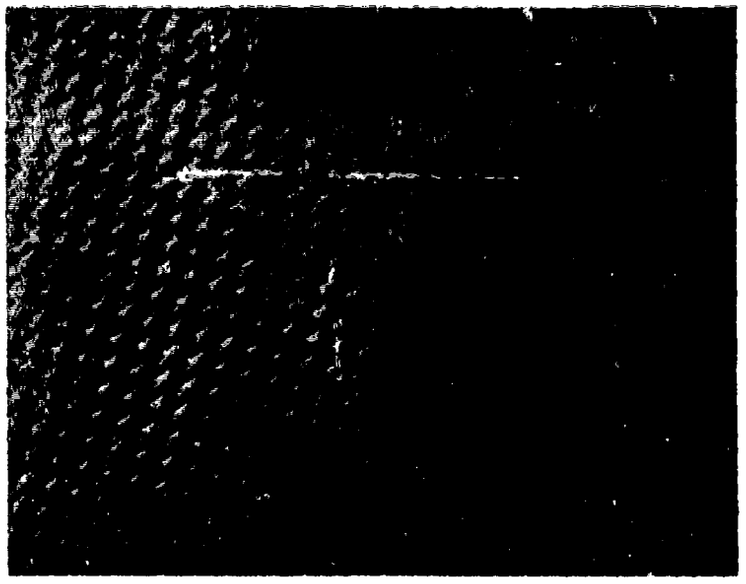
8μm 4X



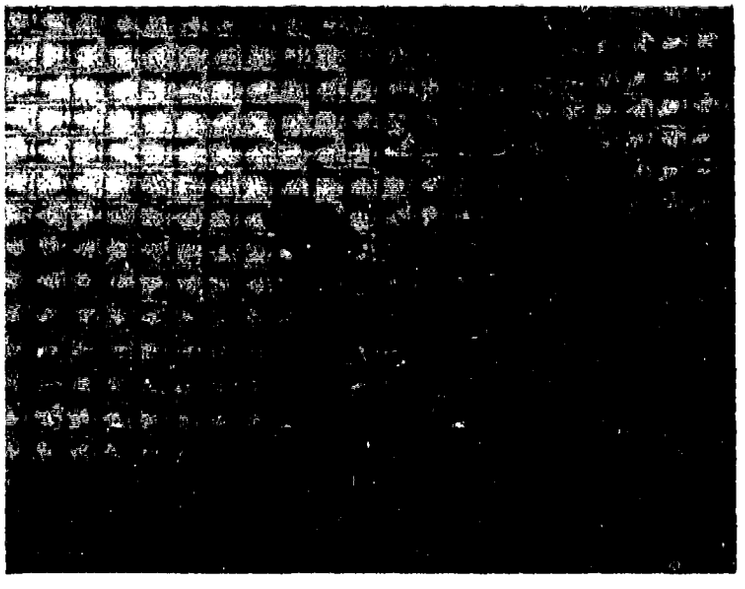
0.45μm 4X

APPENDIX B-3
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6614

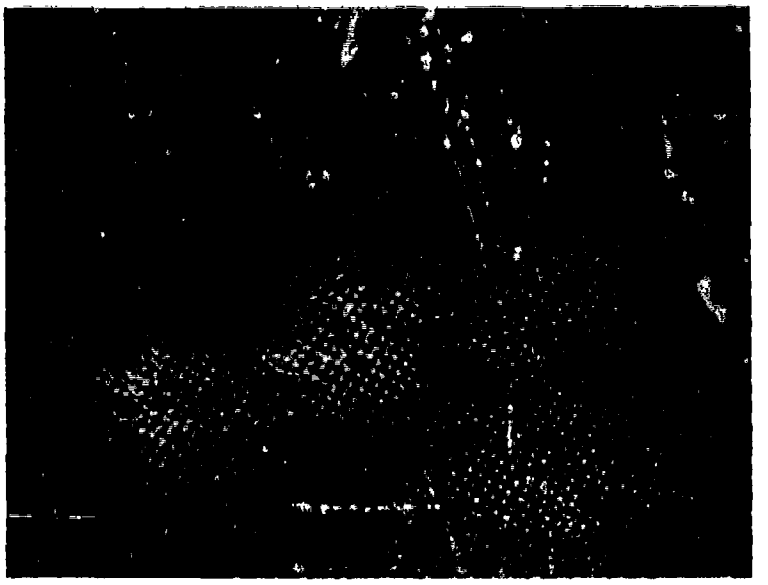
AH-1G, 71-21031 Front Drain
(See Table 9)



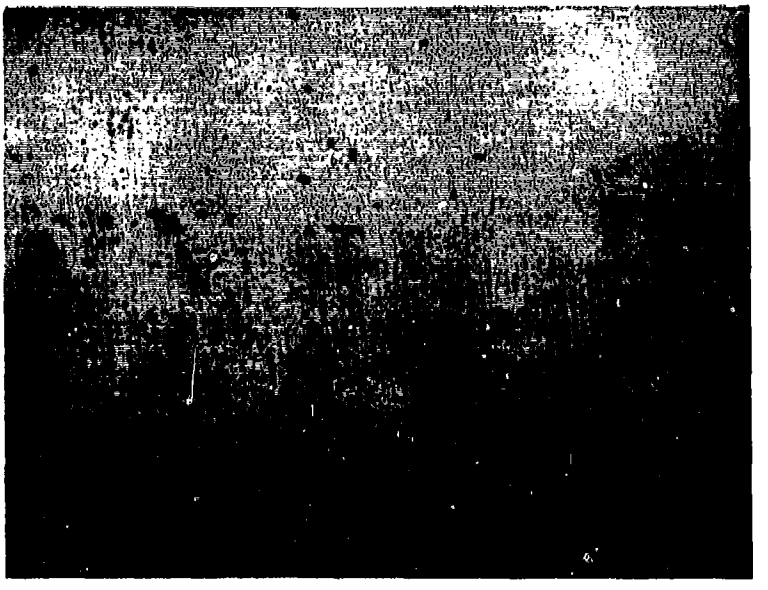
1000μm 4X



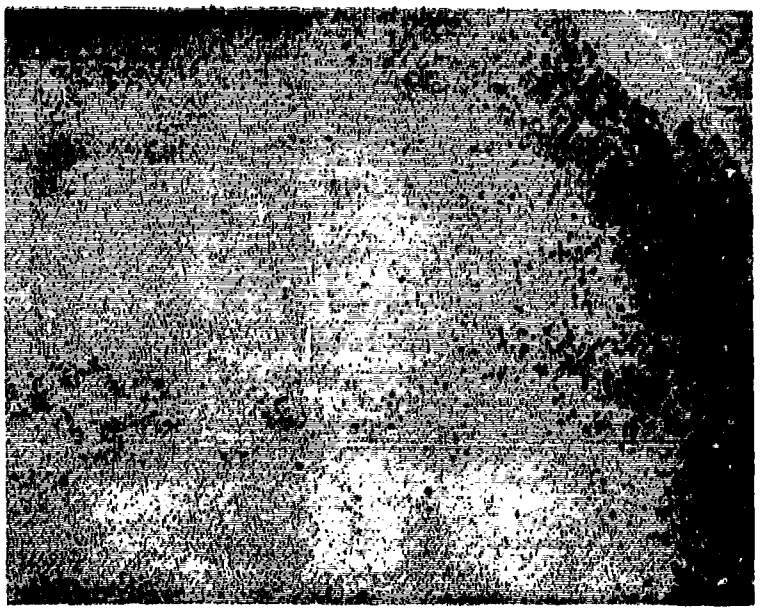
500μm 4X



300μm 4X



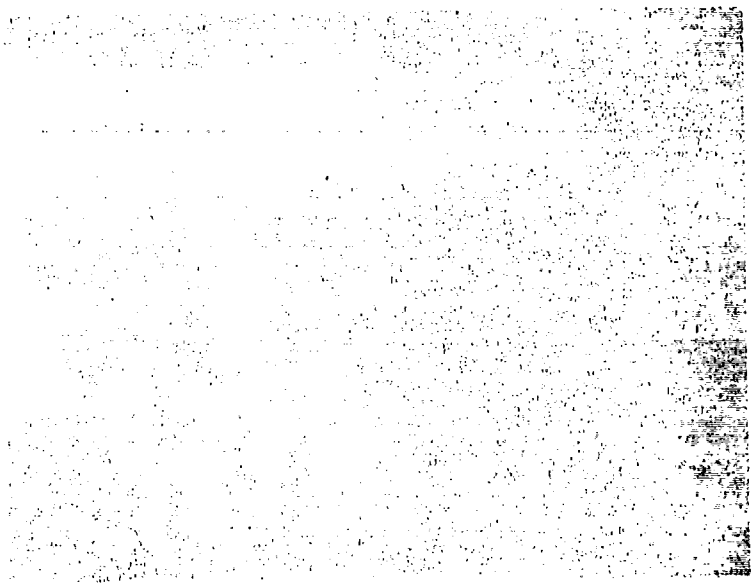
102μm 4X



52μm 4X

26μm 4X

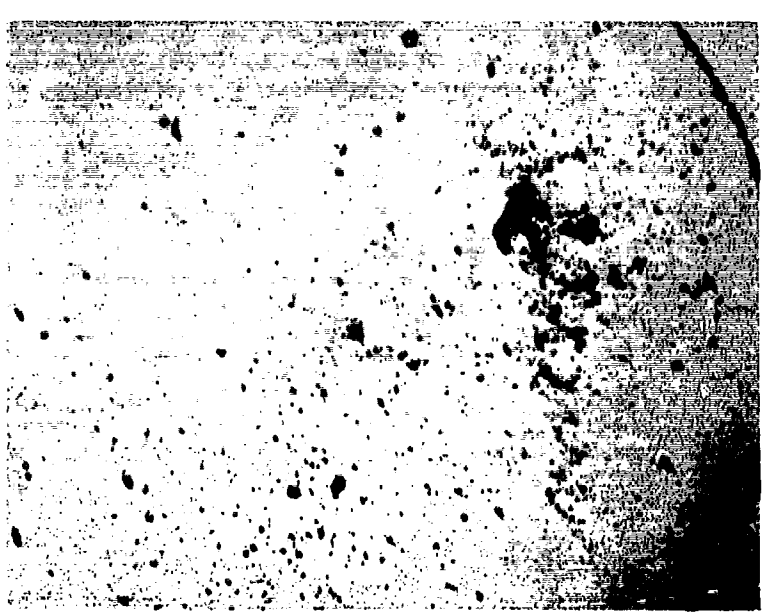
8μm 4X



0.45μm 4X

APPENDIX B-4
8-μm FILTRATION PHOTOMICROGRAPHS
REFORGER–AIRCRAFT

(See Table 8)

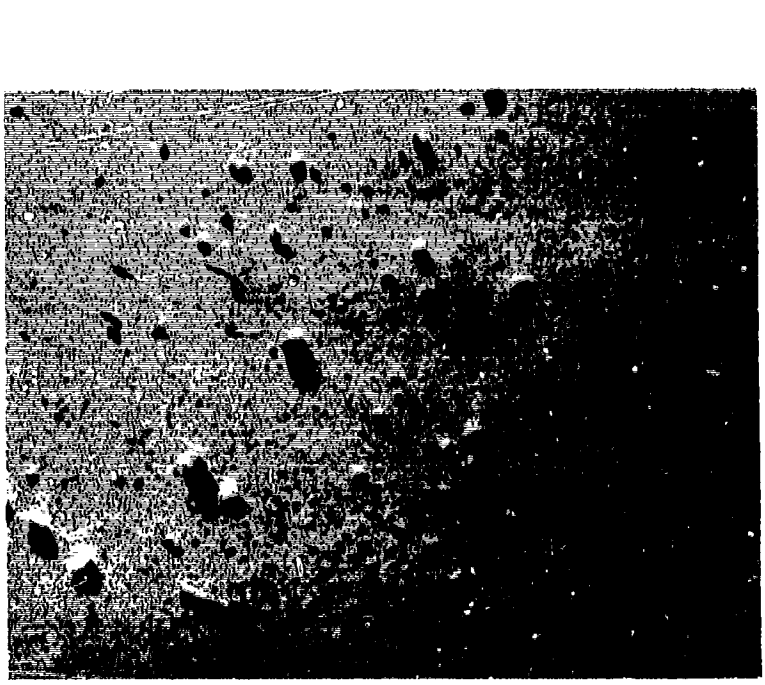


8μ 4X

SAMPLE 6578
UH-1H, 71-20142 (LF)

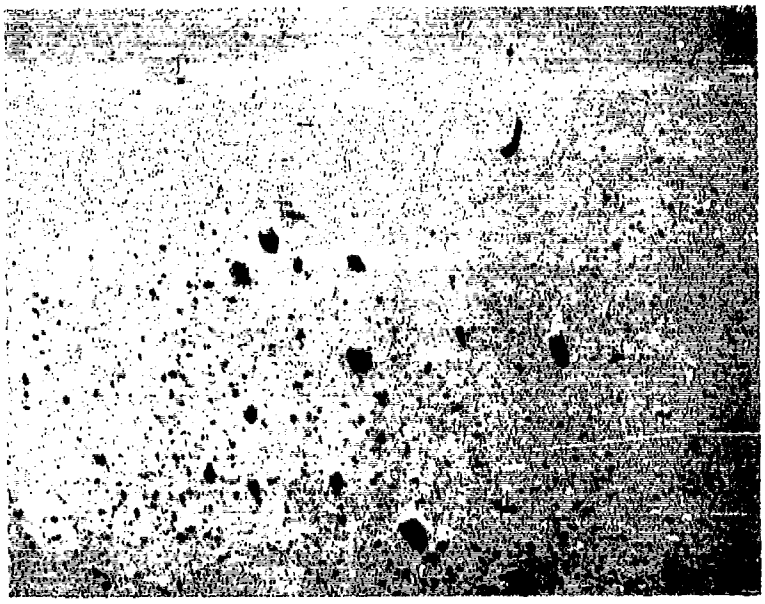
8μ 4X

SAMPLE 6580
AH-1G, 67-15721 (F)



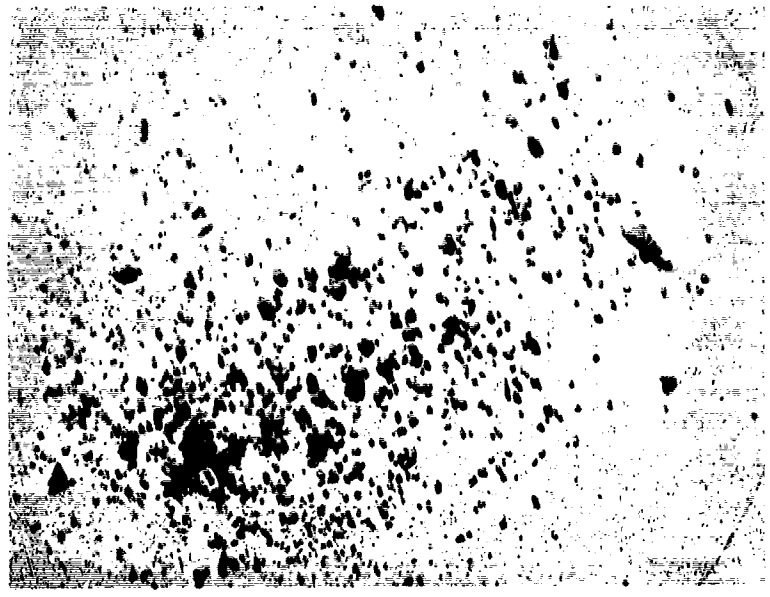
8μ 4X

SAMPLE 6587
UH-1H, 67-17672 (LF)



8μ 4X

SAMPLE 6588
UH-1H, 67-17672 (RF)

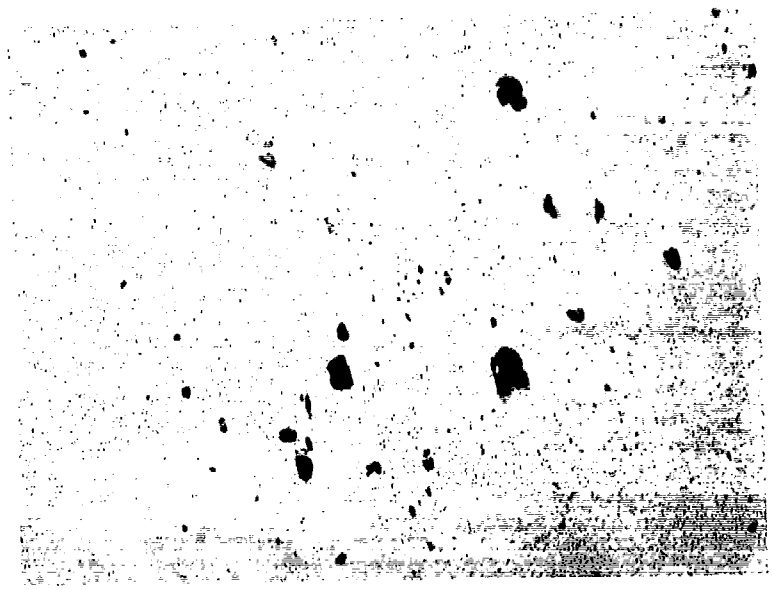


8μ 4X

SAMPLE 6589
OH-58A, 68-16977

8μ 4X

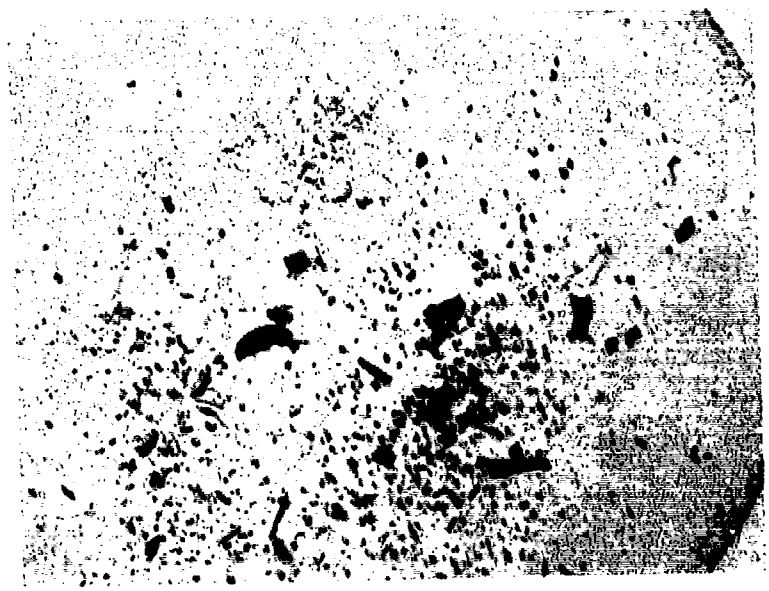
SAMPLE 6601
OH-58A, 70-15561



8μ

4X

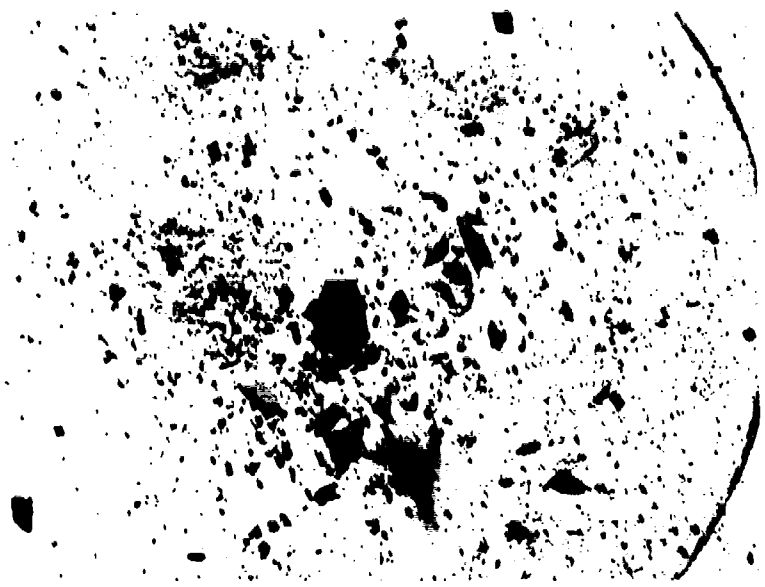
SAMPLE 6604
OH-58A, 70-15172



8μ

4X

SAMPLE 6615
OH-58A, 71-20838



8μ 4X

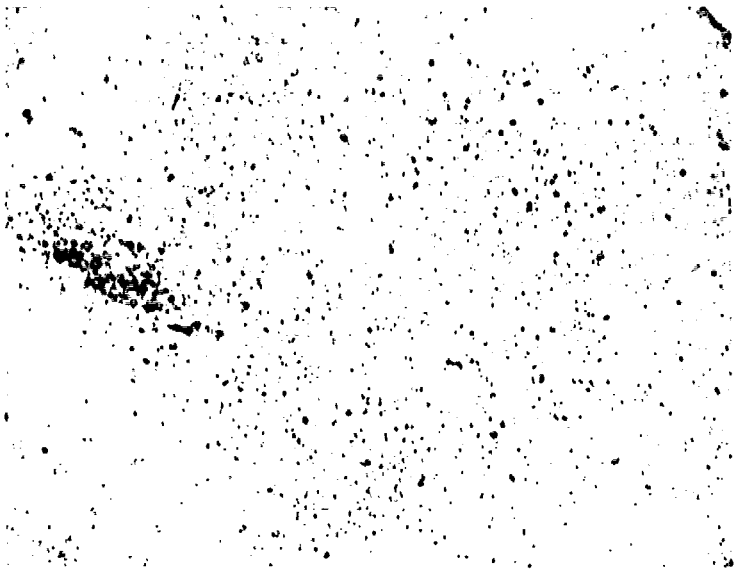
SAMPLE 6621
CH-47C, 69-17126 (LF)

8μ 4X

SAMPLE 6622
CH-47C, 69-17126 (RF)

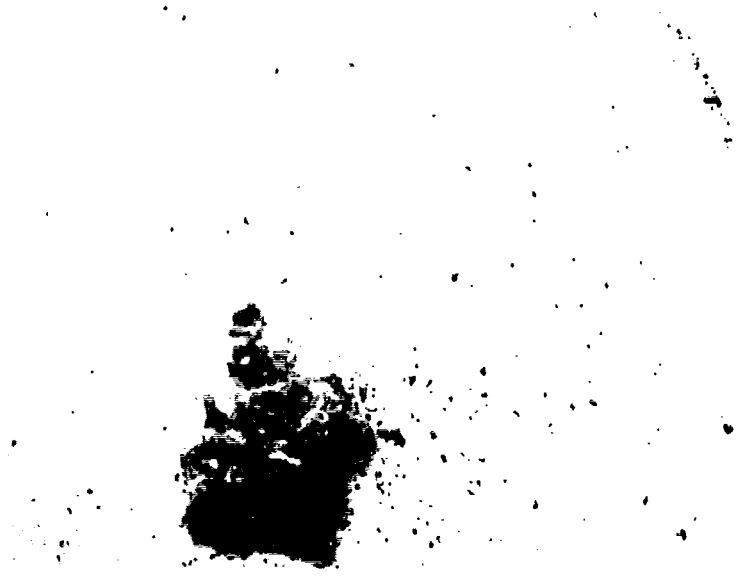
APPENDIX B-5
8-μm FILTRATION PHOTOMICROGRAPHS
REFORGER--FUEL SUPPLY POINTS

(See Table 8)



8μ 4X

SAMPLE 6596
Bladder No. 2, POL Rapid Refill Point
(at filter separator after filtration)



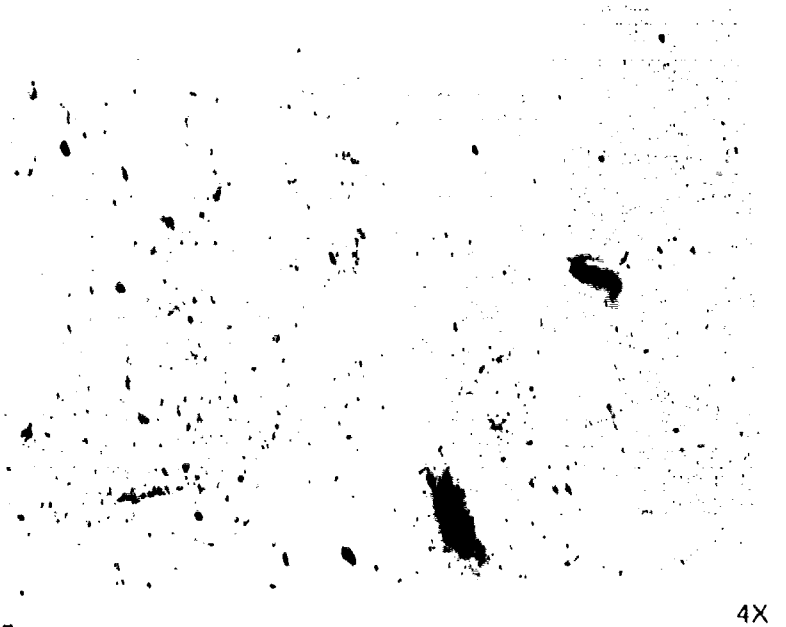
8μ 4X

SAMPLE 6600
Railway Tank Car, 00/ 0-323 9P
(at filter separator after filtration)

APPENDIX C
FILTRATION PHOTOMICROGRAPHS FOR OPERATION BRAVE SHIELD XIV

APPENDIX C-1
8-μm FILTRATION PHOTOMICROGRAPHS
BRAVE SHIELD XIV—AIRCRAFT

(See Table 7)



8μ 4X

SAMPLE 6546
UH-1H, 74-22495 (LF)

8μ 4X

SAMPLE 6547
OH-58A, 71-20806

8μ 4X

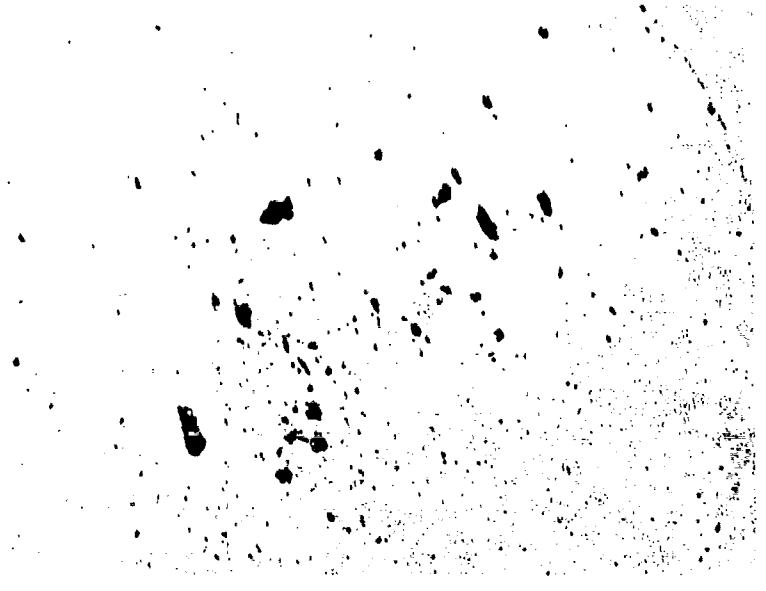
SAMPLE 6549
OH-58A, 71-20444

8μ 4X

SAMPLE 6550
OH-58A, 71-21087

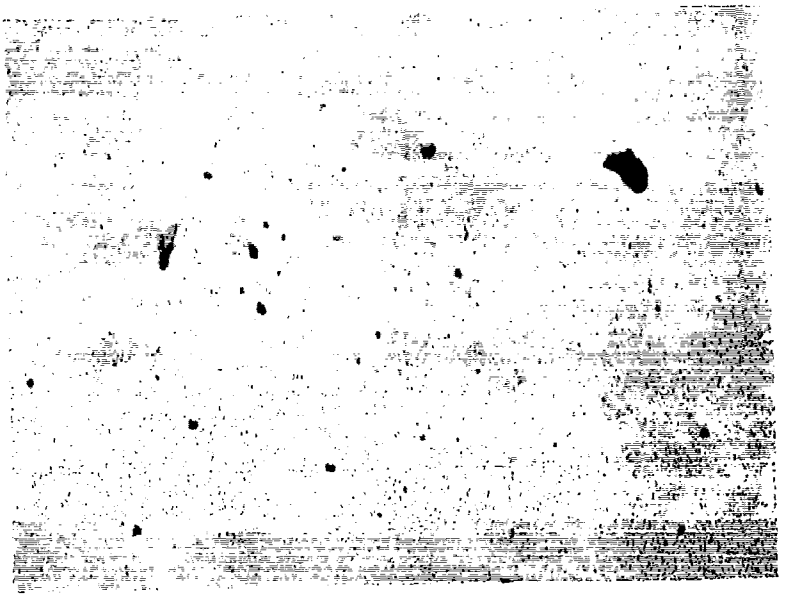
8μ 4X

SAMPLE 6554
OH-58A, 71-20763



8μ 4X

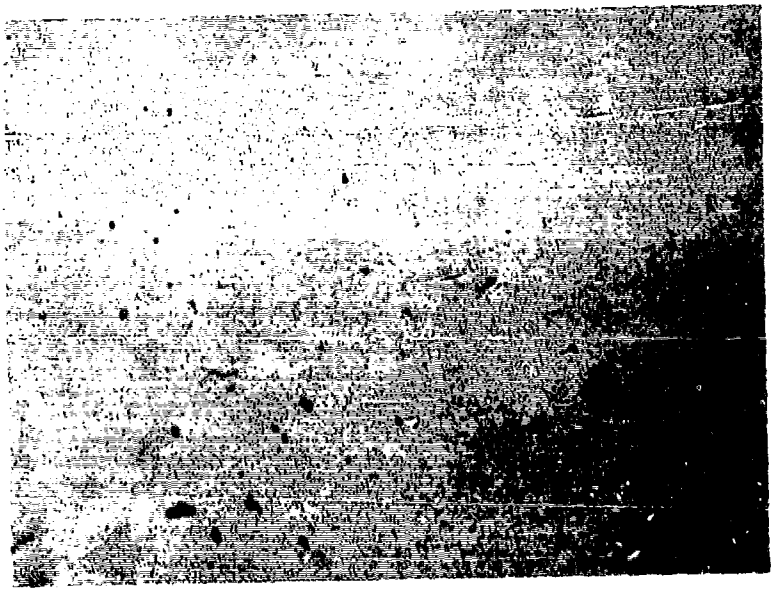
SAMPLE 6555
OH-58A, 71-20586



8μ

4X

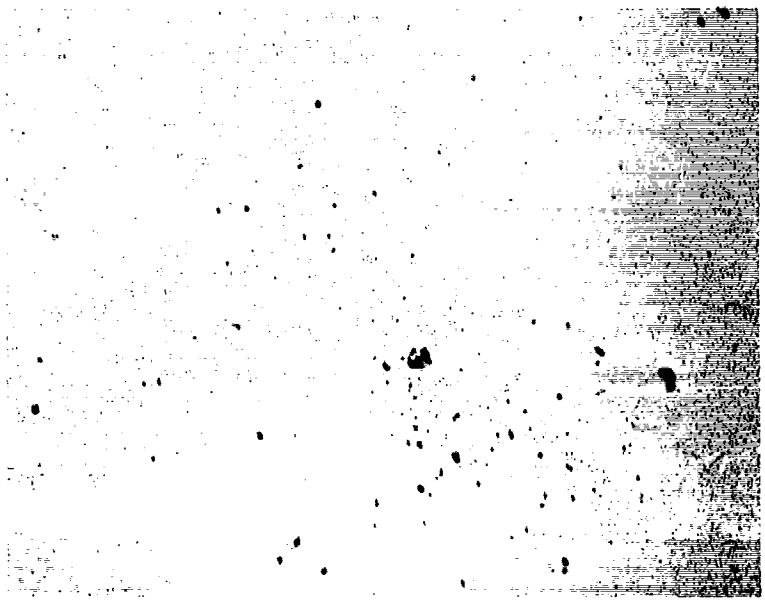
SAMPLE 6559
OH-58A, 70-15254



8μ

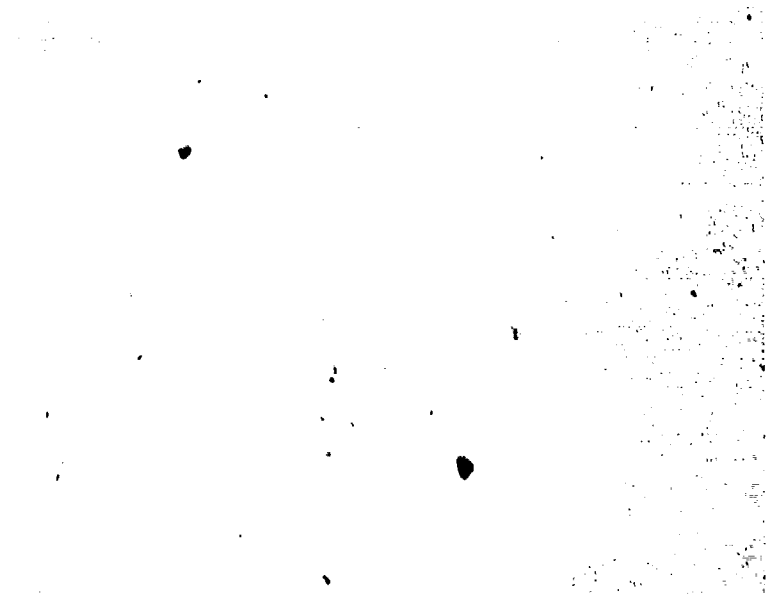
4X

SAMPLE 6560
UH-1H, 68-16239 (LF)



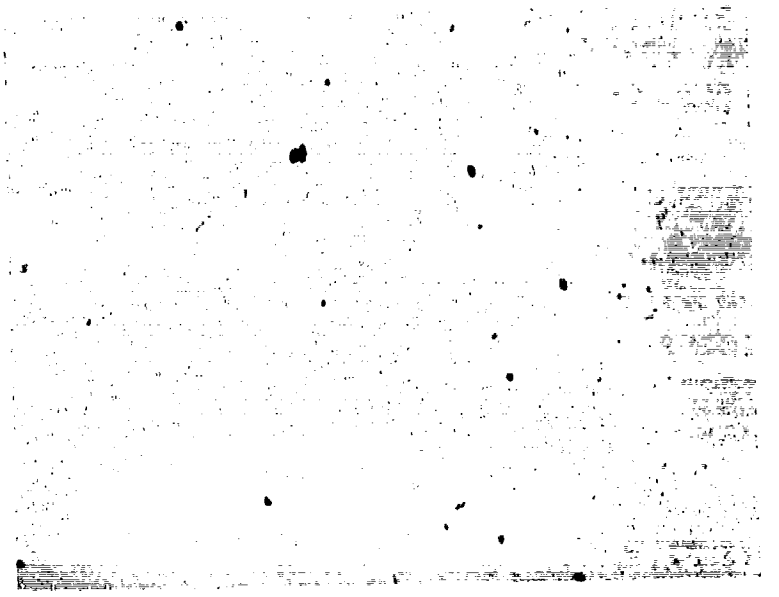
8μ 4X

SAMPLE 6562
UH-1H, 66-00856 (LF)



8μ 4X

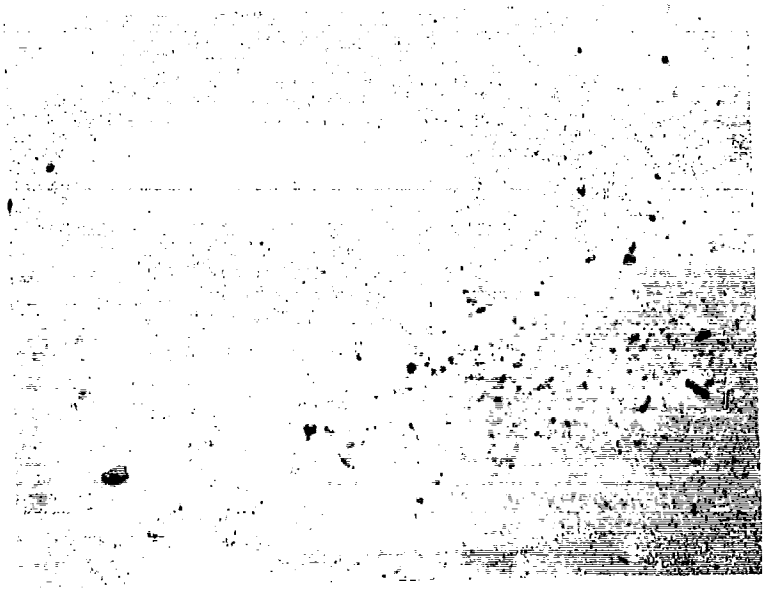
SAMPLE 6563
UH-1H, 65-9967 (LF)



8μ

4X

SAMPLE 6565
OH-58A, 70-15311



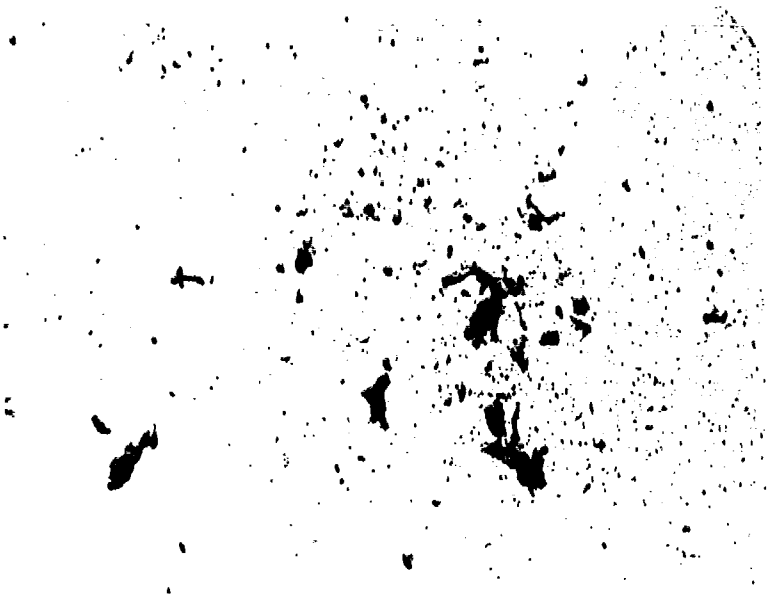
8μ

4X

SAMPLE 6567
UH-1H, 73-21786 (LF)

APPENDIX C-2
8-μm FILTRATION PHOTOMICROGRAPHS
BRAVE SHIELD XIV--TANK TRUCKS

(See Table 7)



8μ 4X

SAMPLE 6561
Truck No. 2
(Rear Cell, after filtration)

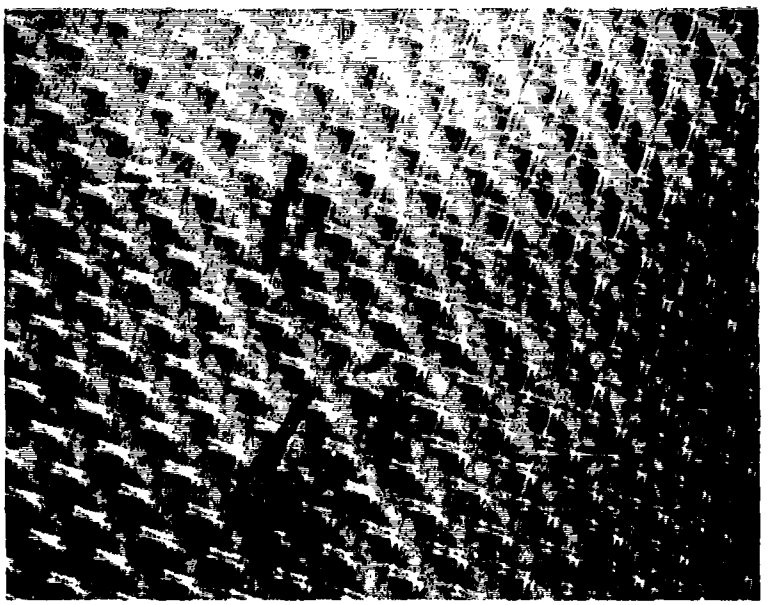
8μ 4X

SAMPLE 6566
Truck No. 3
(Nozzle Sample)

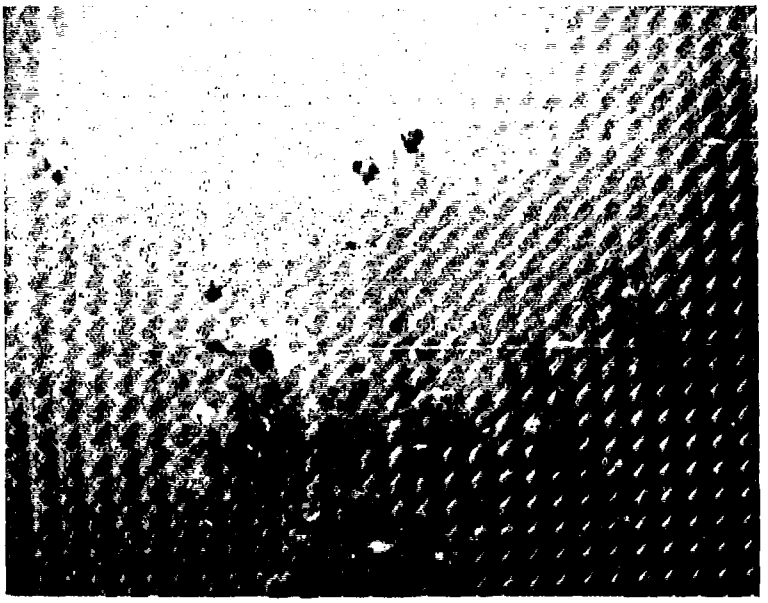
APPENDIX D
FILTRATION PHOTOMICROGRAPHS FOR OPERATION BRAVE SHIELD XV

APPENDIX D-1
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6664

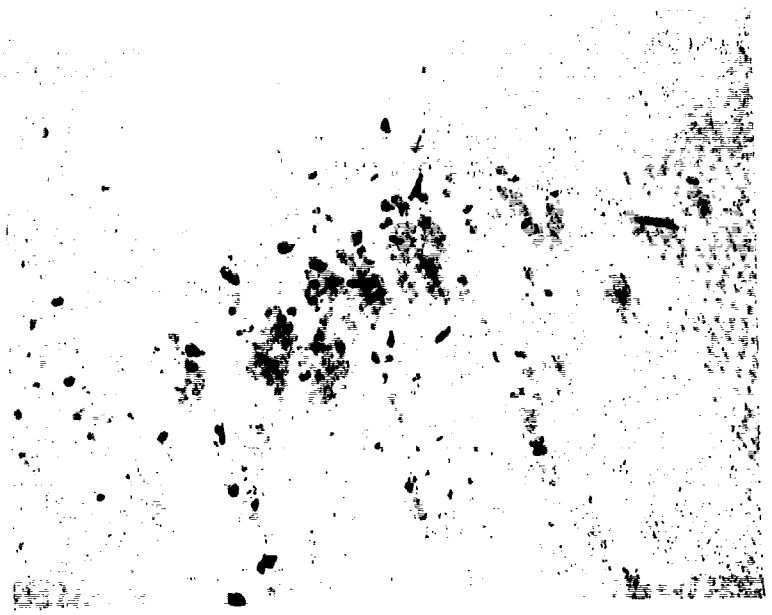
OH-58A, 70-15613
(See Table 11)



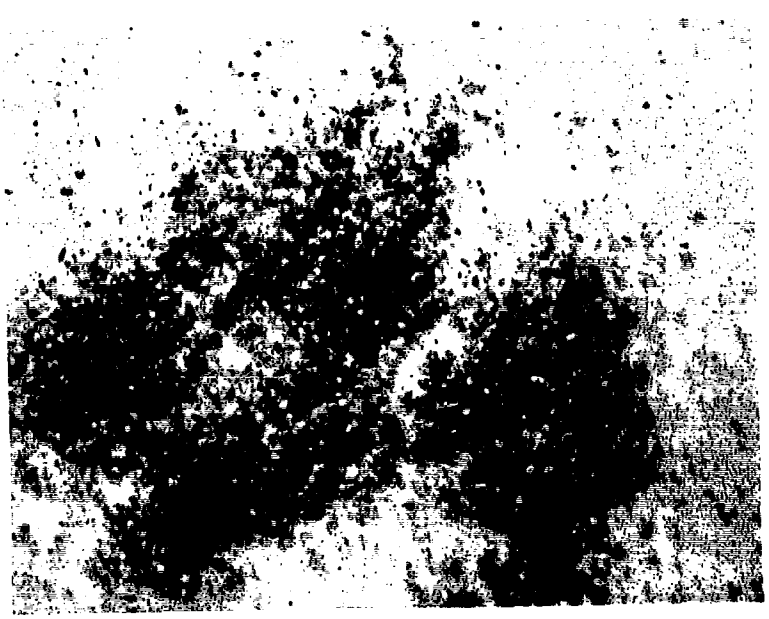
1000μm 4X



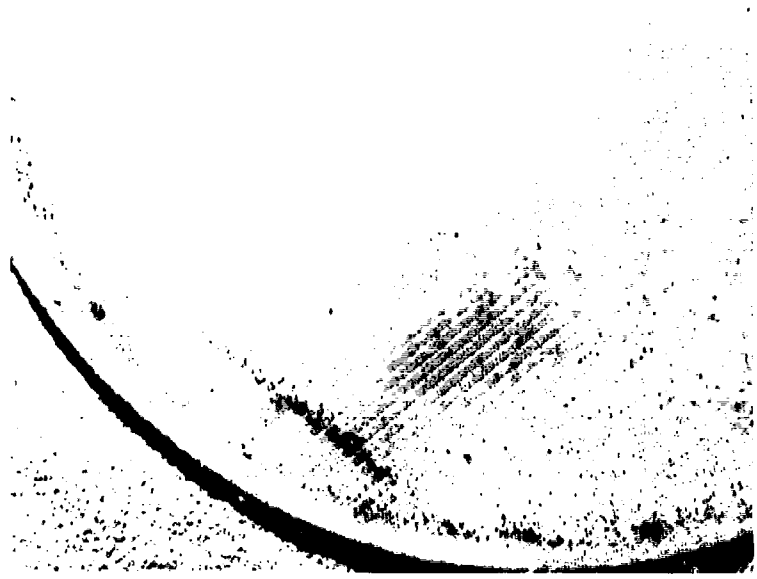
500μm 4X



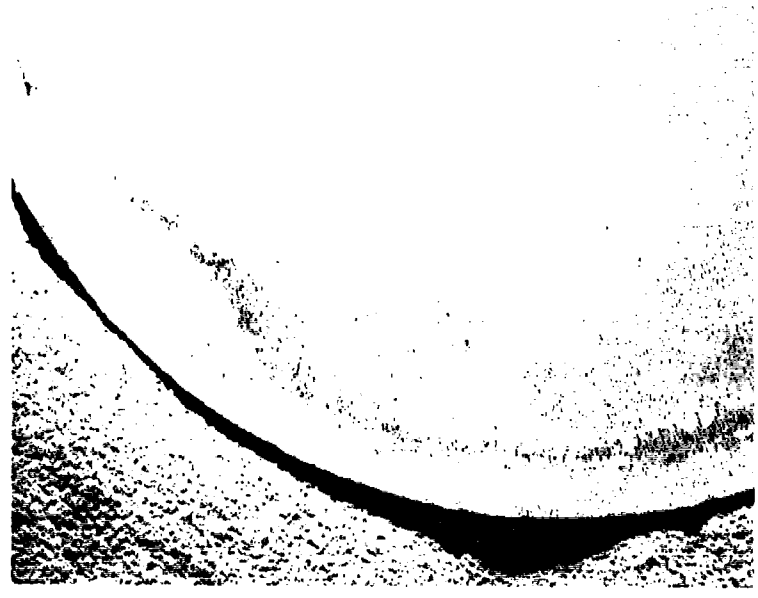
300μm 4X



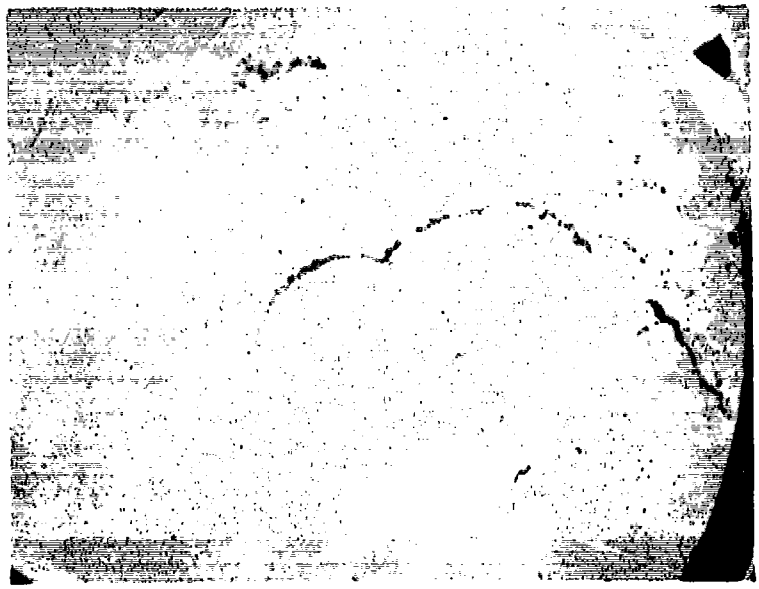
102μm 4X



52μm 4X



26μm 4X



8μm 4X

0.45μm 4X

APPENDIX D-2
SAMPLE NO. 6665

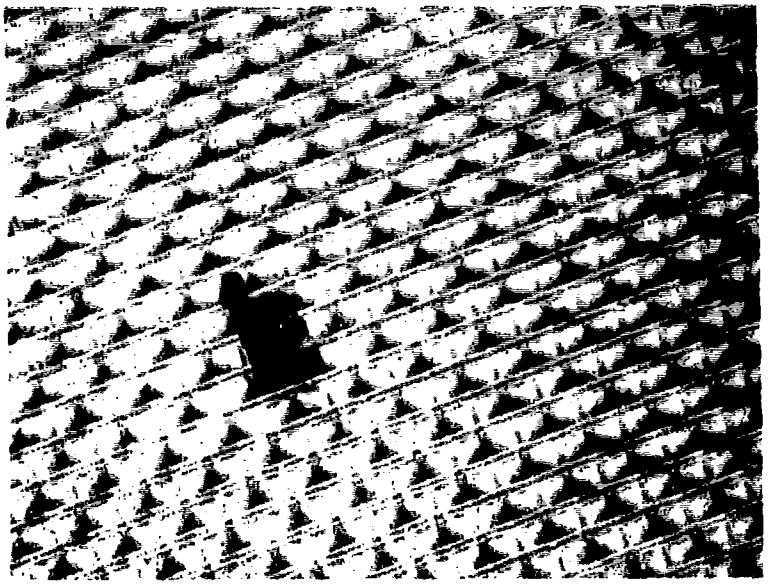
OH-58A, 72-21194
(See Table 11)

8μm 4X

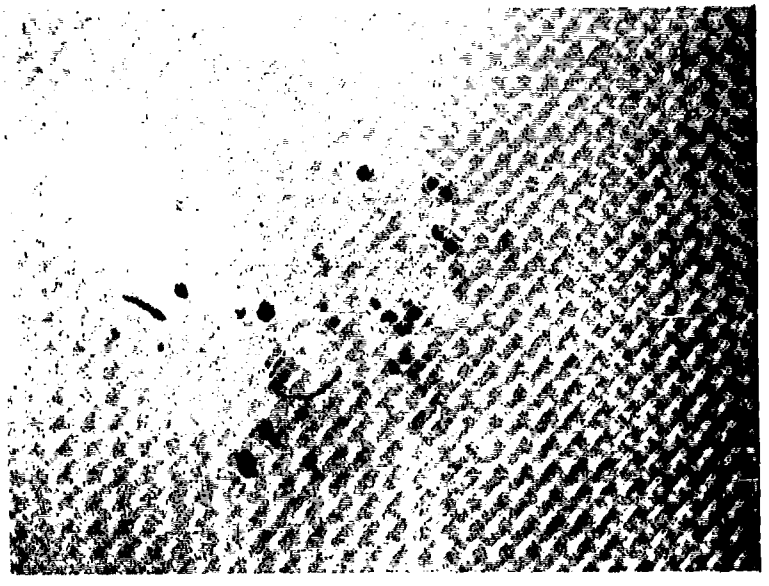
SAMPLE 6665

APPENDIX D-3
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. *6666*

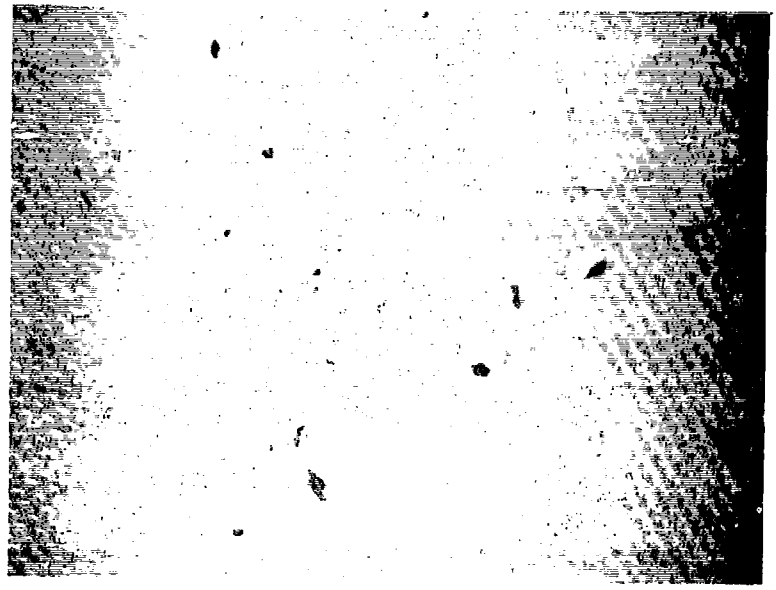
OH-58A, 70-15150
(See Table 11)



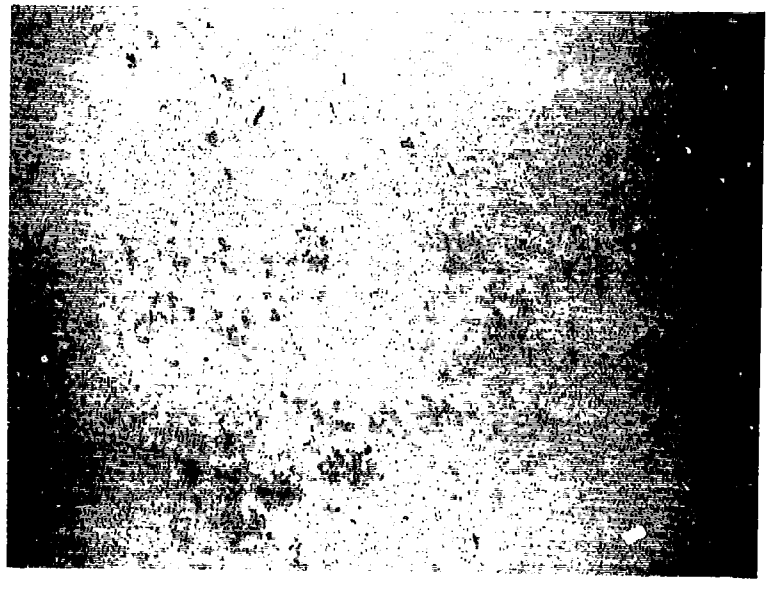
1000μm 4X



500μm 4X



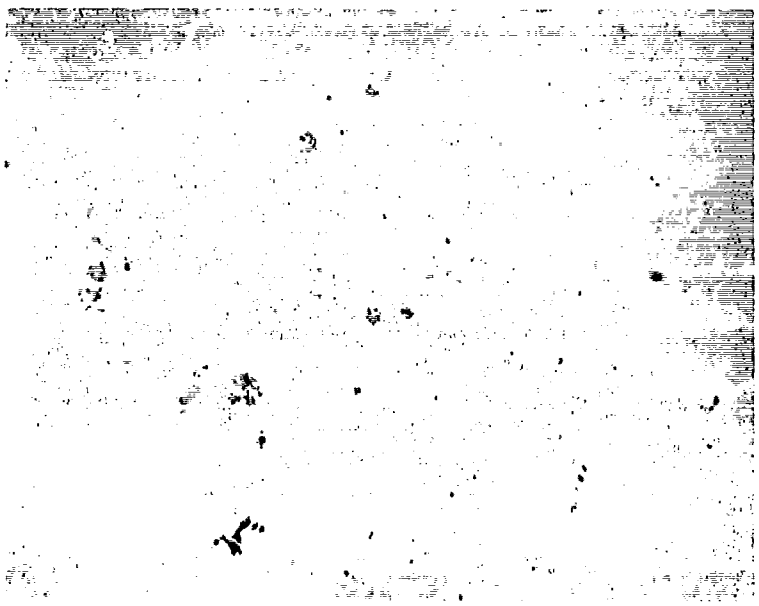
300μm 4X



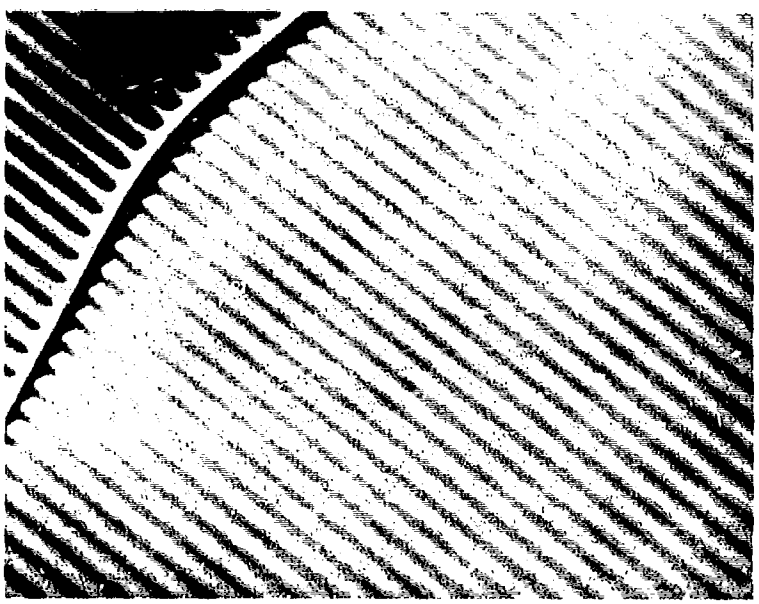
102μm 4X

52μm 4X

26μm 4X



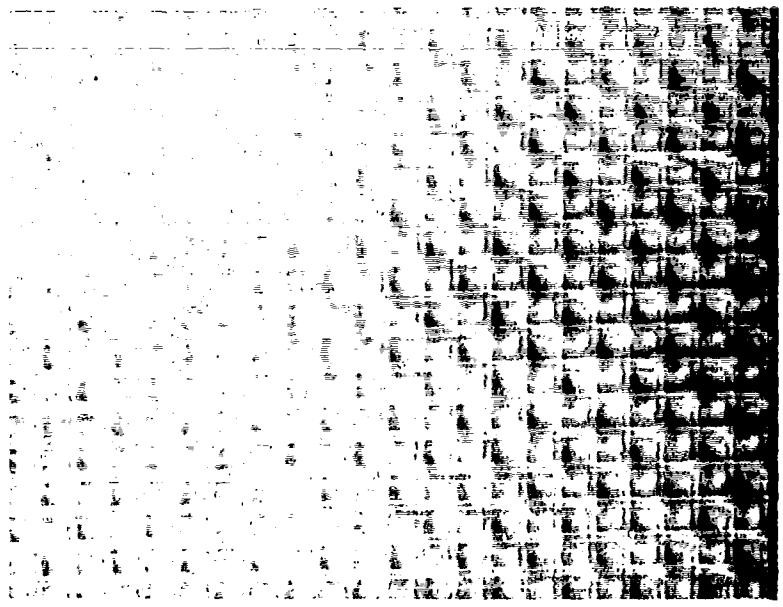
8μm 4X



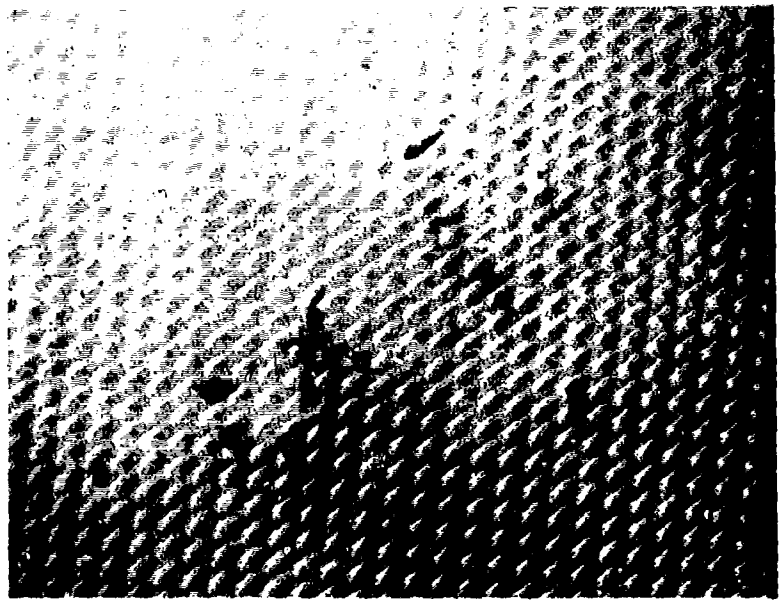
0.45μm 4X

APPENDIX D-4
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6667

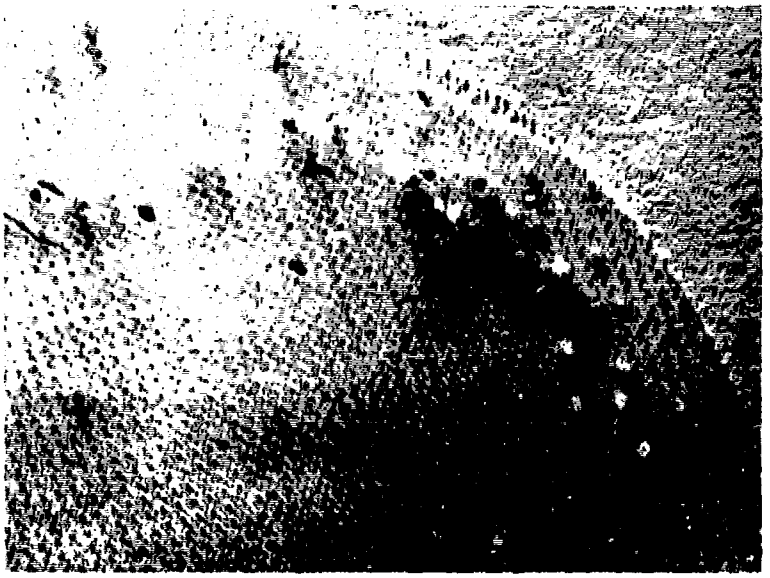
OH-58A, 69-16096
(See Table 11)



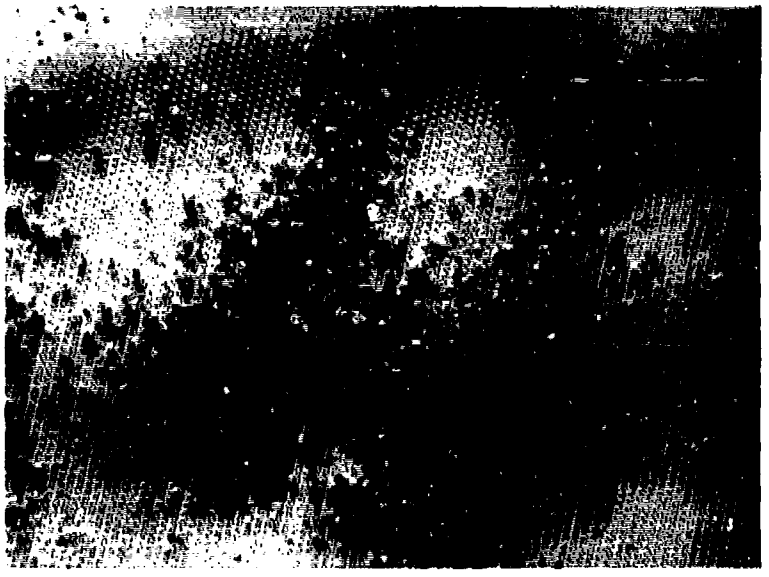
1000μm 4X



500μm 4X



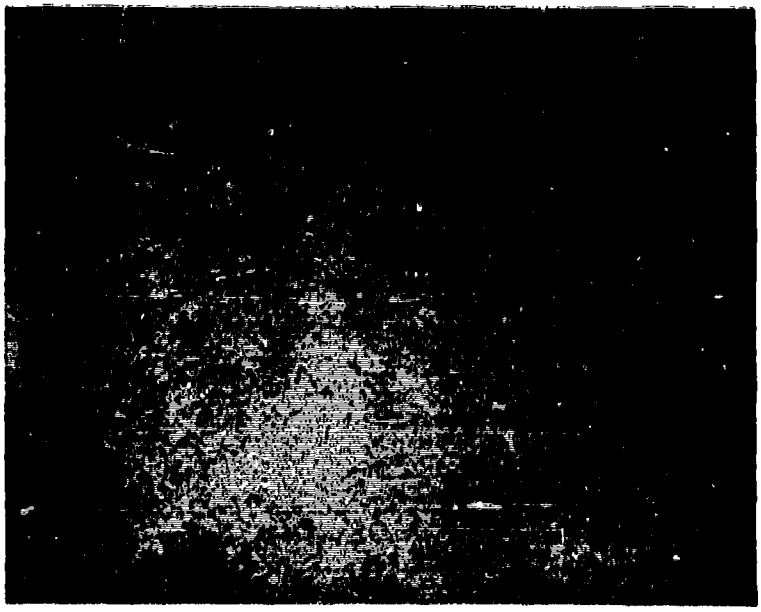
300μm 4X



102μm 4X

52μm 4X

26μm 4X

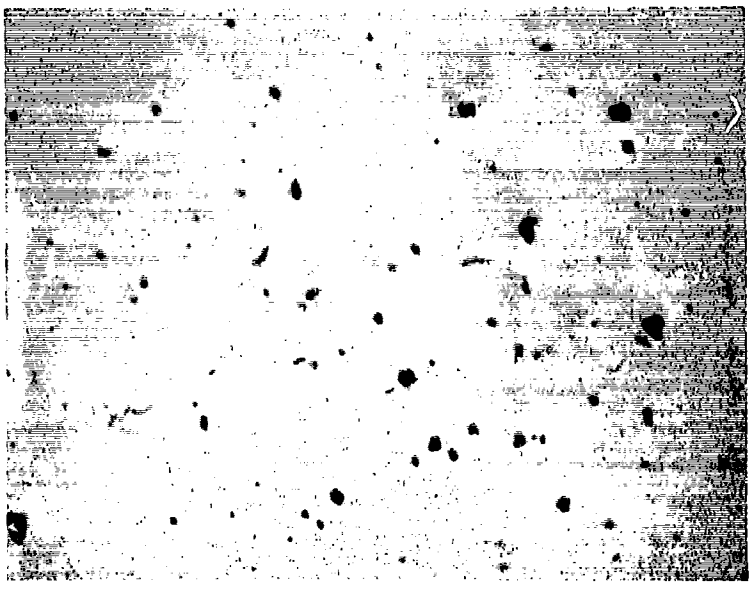


8μm 4X

0.45μm 4X

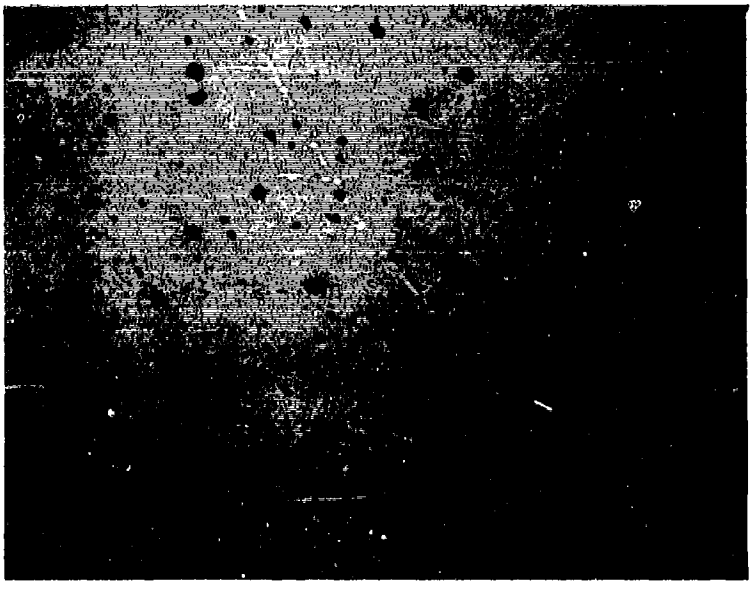
APPENDIX D-5
8-μm FILTRATION PHOTOMICROGRAPHS
BRAVE SHIELD XV—AIRCRAFT

(See Table 10)



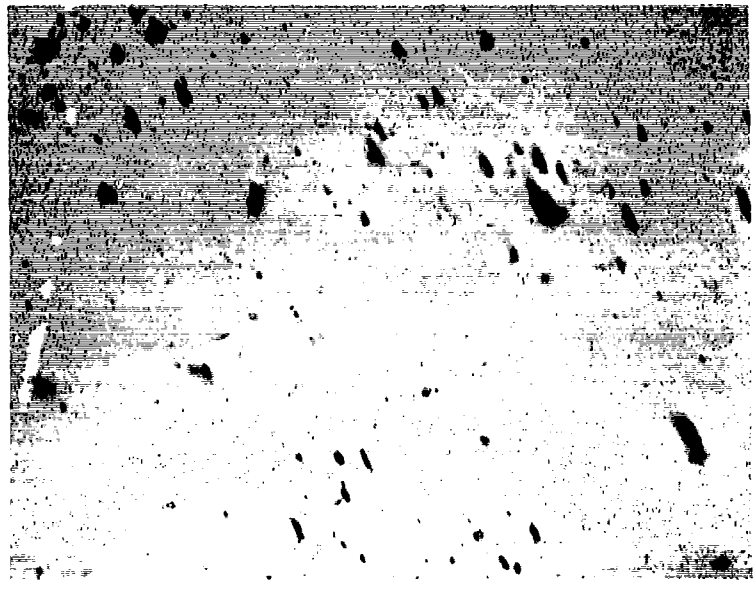
8μ 4X

SAMPLE 6642
UH-1H, 70-16293 (LF)



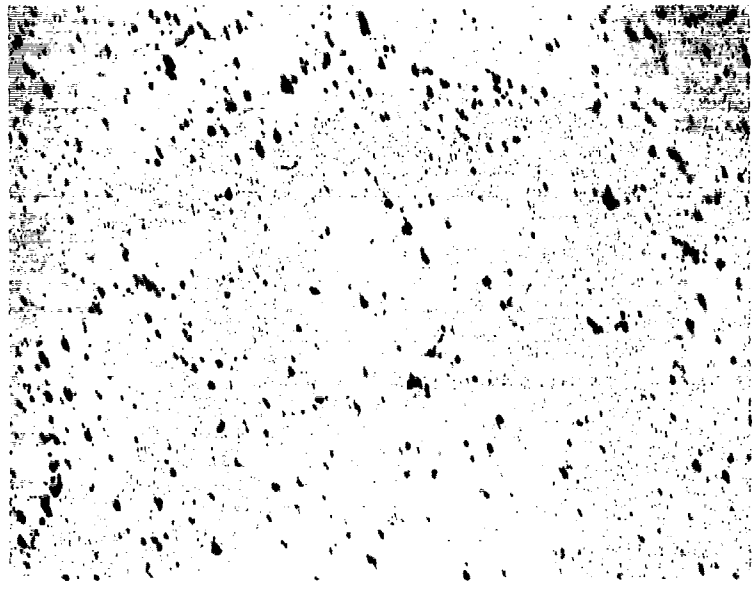
8μ 4X

SAMPLE 6643
UH-1H, 70-16293 (RF)



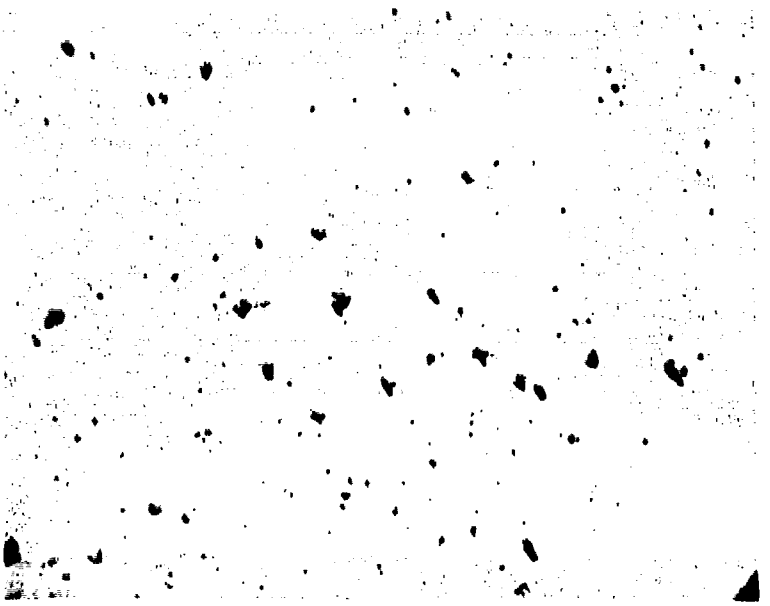
8μ 4X

SAMPLE 6644
UH-1H, 70-16472 (LF)



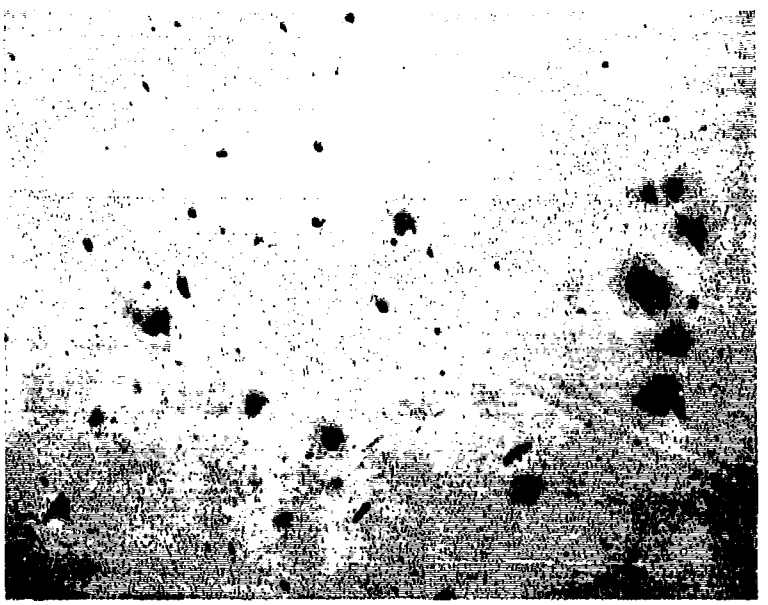
8μ 4X

SAMPLE 6645
UH-1H, 70-16472 (RF)



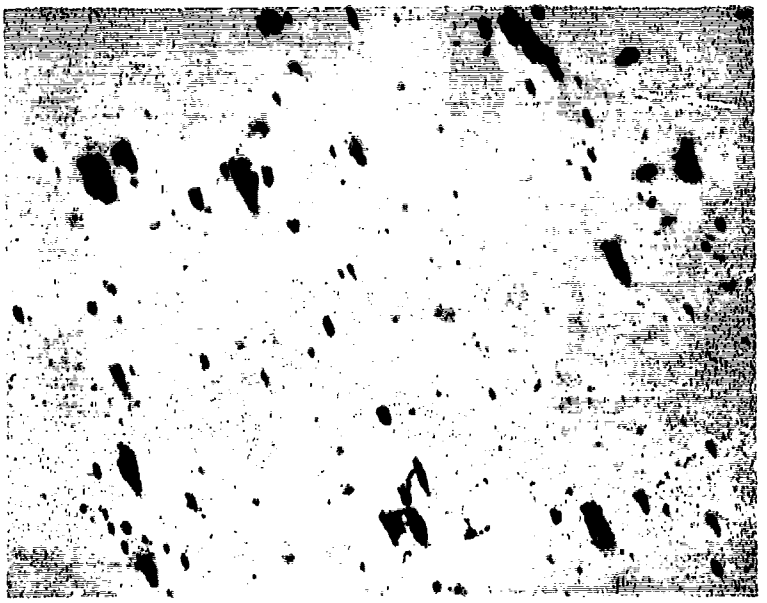
8μ 4X

SAMPLE 6646
UH-1H, 69-15314 (LF)



8μ 4X

SAMPLE 6647
UH-1H, 69-15314 (RF)

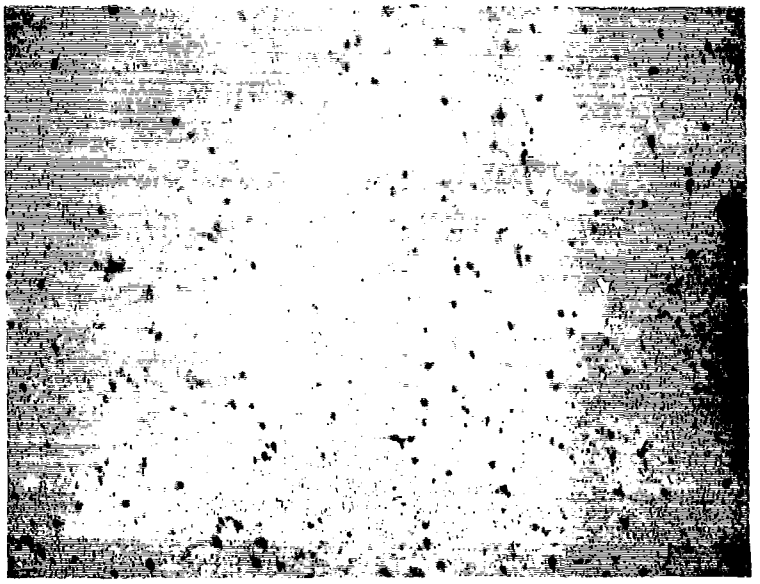


8μ 4X

SAMPLE 6648
UH-1H, 69-15853 (LF)

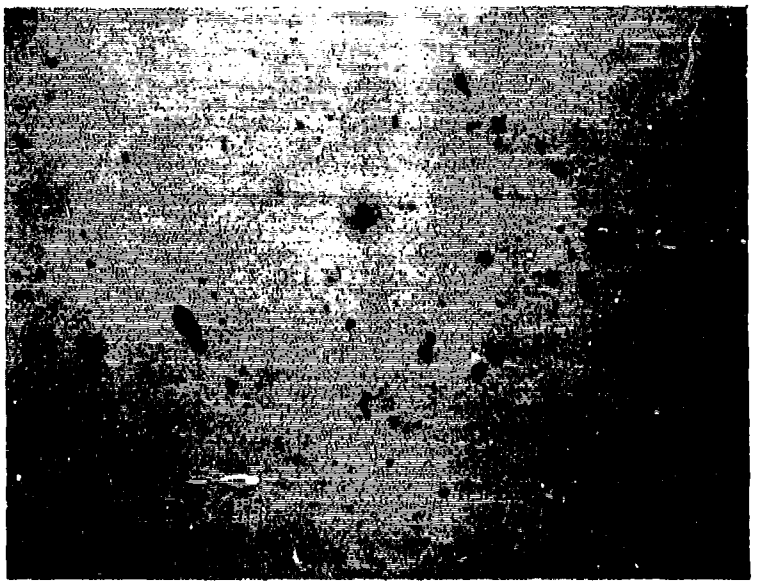
8μ 4X

SAMPLE 6649
UH-1H, 69-15853 (RF)



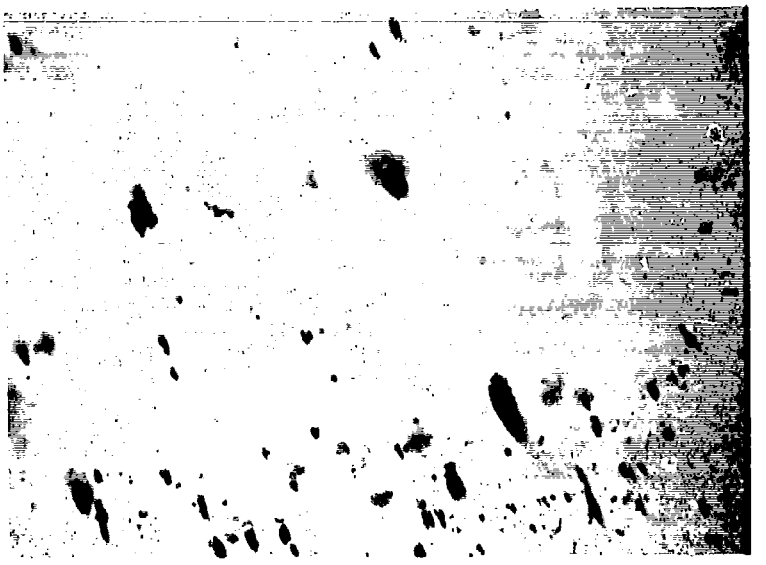
8μ 4X

SAMPLE 6650
UH-1H, 64-13536 (LF)



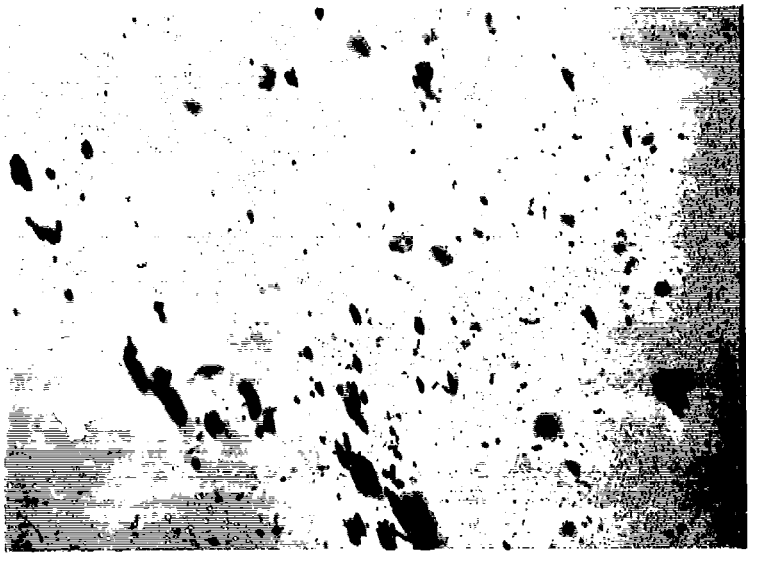
8μ 4X

SAMPLE 6651
UH-1H, 64-13536 (RF)



8μ 4X

SAMPLE 6654
UH-1H, 69-16000 (LF)

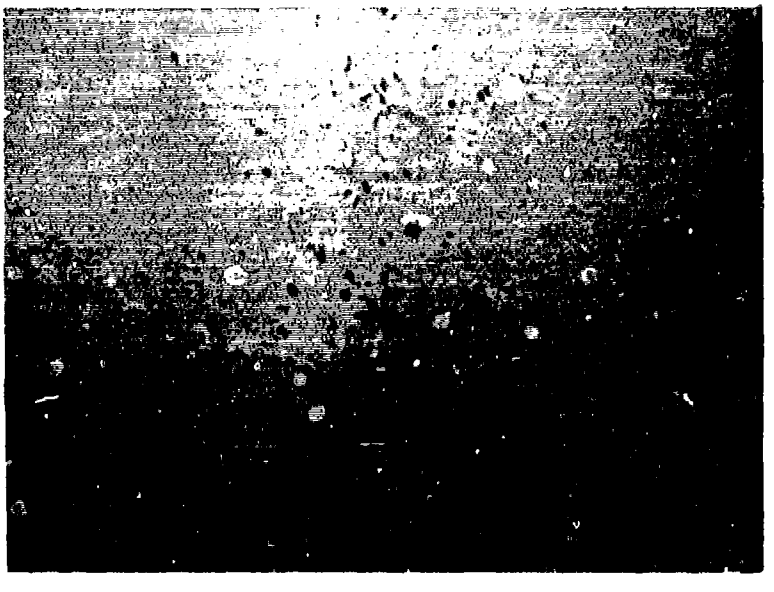


8μ 4X

SAMPLE 6655
UH-1H, 69-16000 (RF)

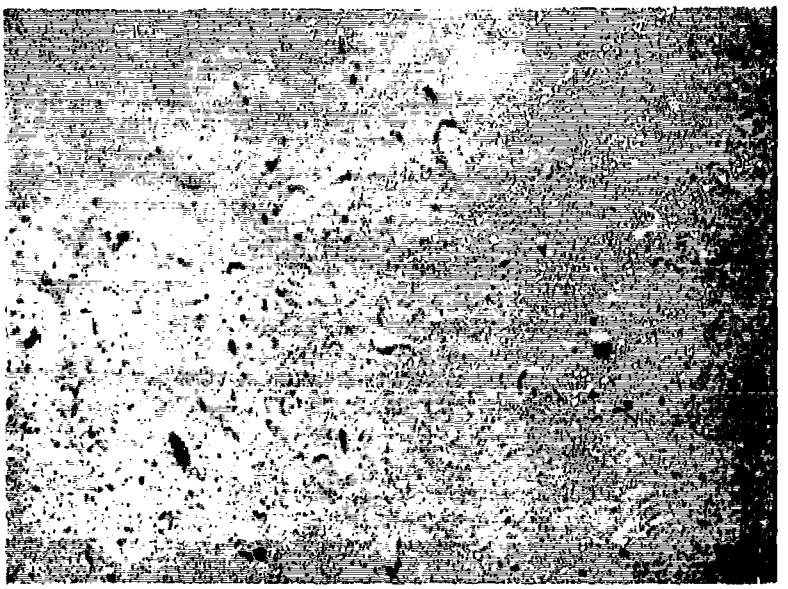
8μ 4X

SAMPLE 6656
UH-1H, 69-15315 (LF)



8μ 4X

SAMPLE 6657
UH-1H, 69-15315 (RF)

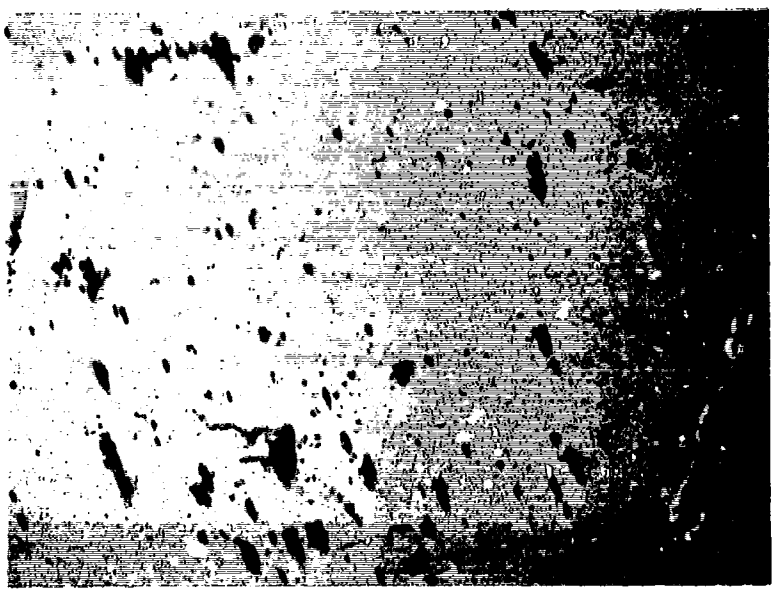


8μ 4X

SAMPLE 6658
UH-1H, 65-9749 (LF)

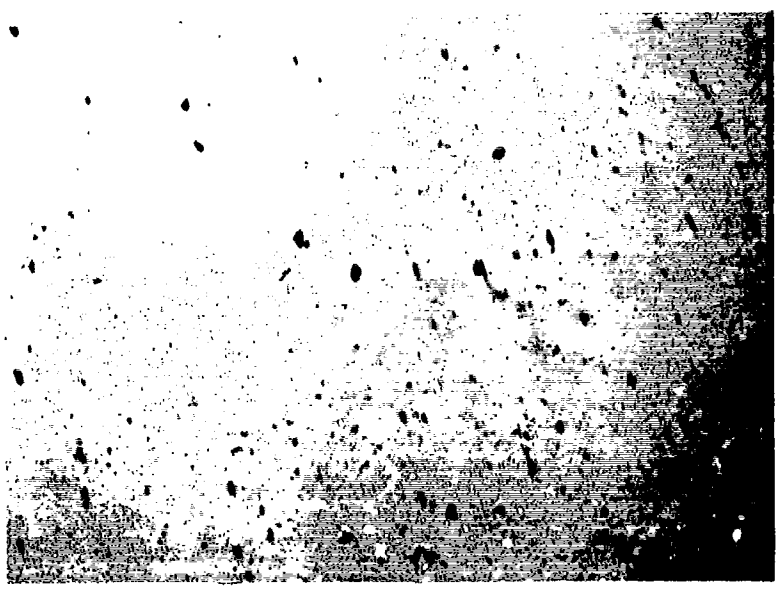
8μ 4X

SAMPLE 6659
UH-1H, 65-9749 (RF)



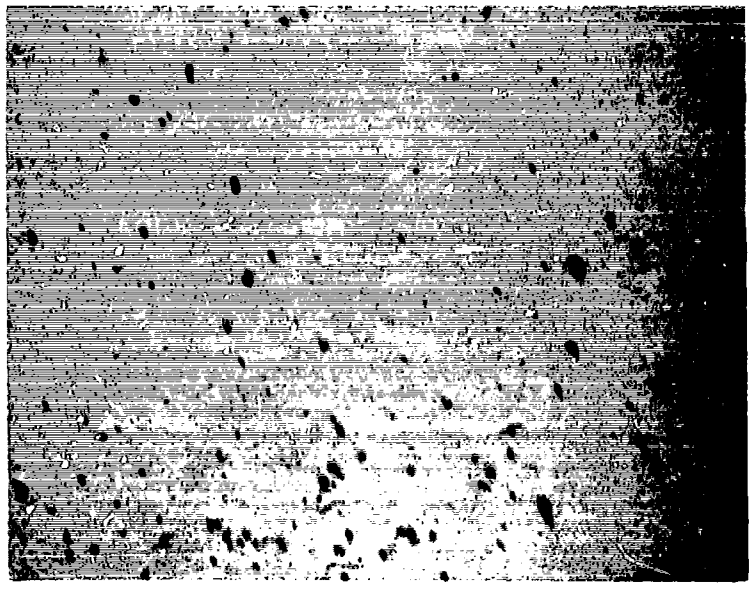
8μ 4X

SAMPLE 6660
UH-1H, 70-16470 (LF)



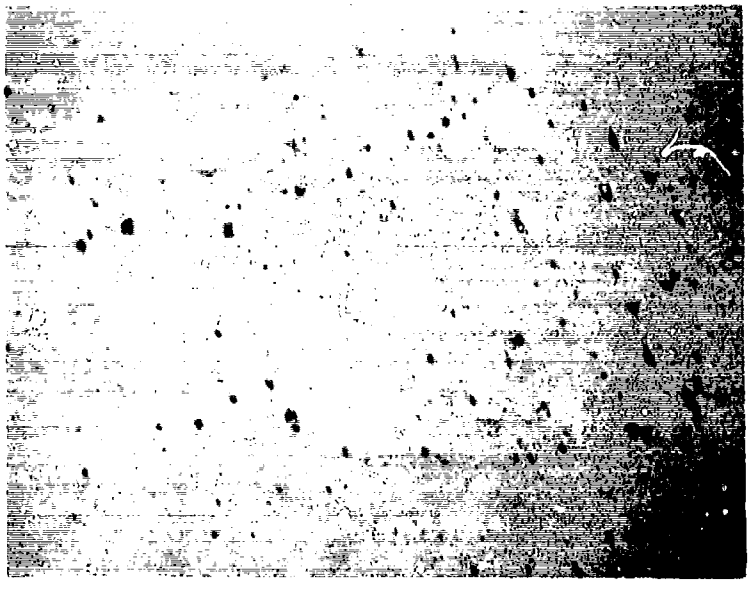
8μ 4X

SAMPLE 6661
UH-1H, 70-16470 (RF)



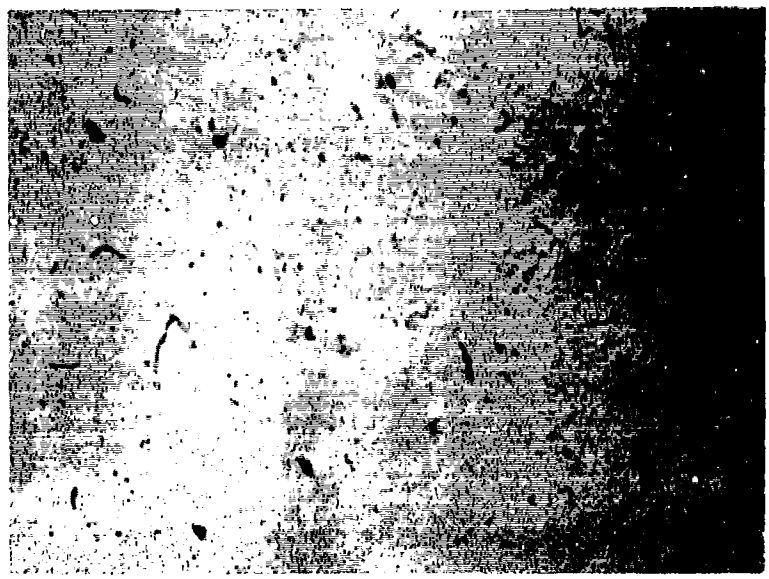
8μ 4X

SAMPLE 6662
UH-1H, 69-15318 (LF)



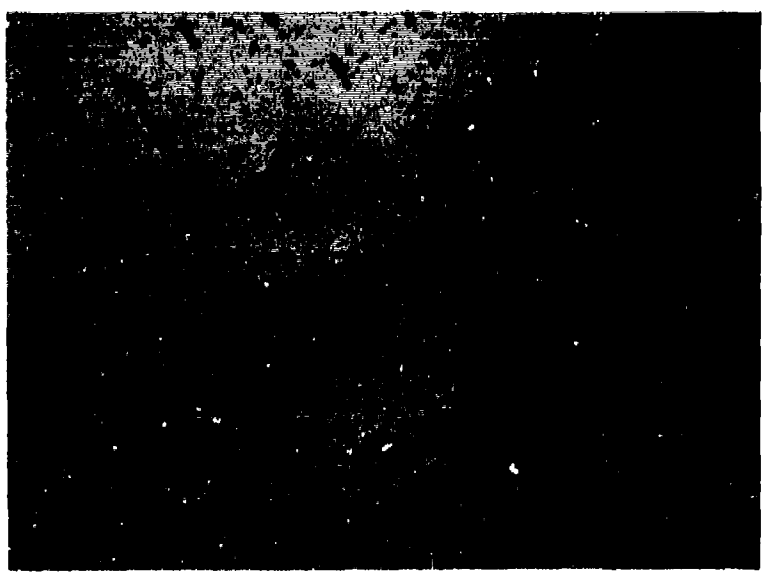
8μ 4X

SAMPLE 6663
UH-1H, 69-15318 (RF)



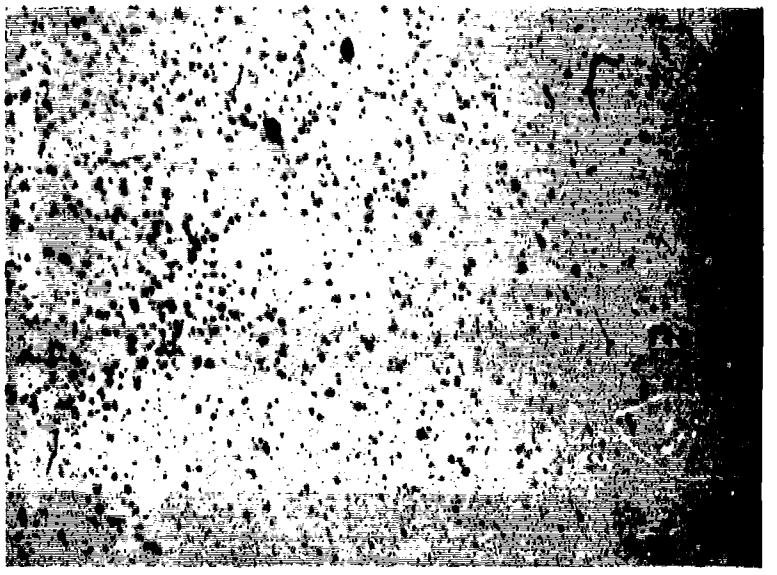
8μ 4X

SAMPLE 6668
CH-54A, 67-18430 (F)



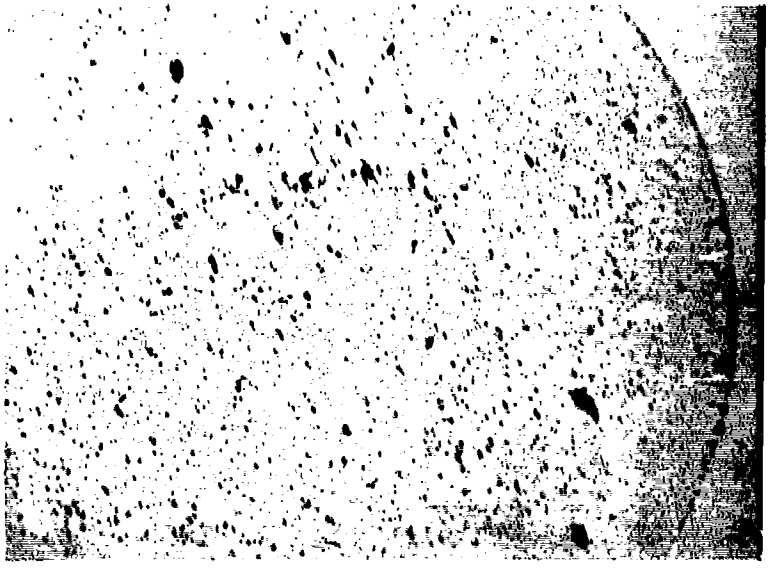
8μ 4X

SAMPLE 6669
CH-54A, 67-18430 (A)



8μ 4X

SAMPLE 6670
CH-54A, 67-18420 (F)



8μ 4X

SAMPLE 6671
CH-54A, 67-18420 (A)

8μ 4X

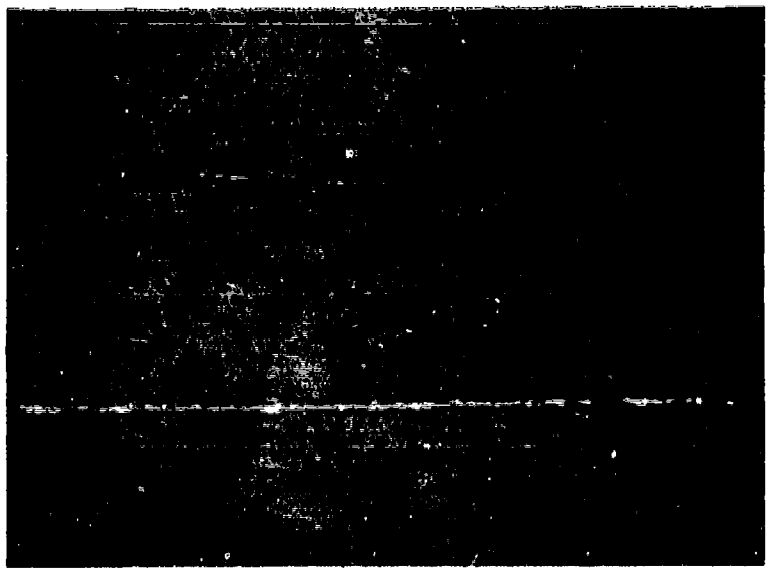
SAMPLE 6672
CH-54A, 67-18424 (F)

8μ 4X

SAMPLE 6673
CH-54A, 67-18424 (A)

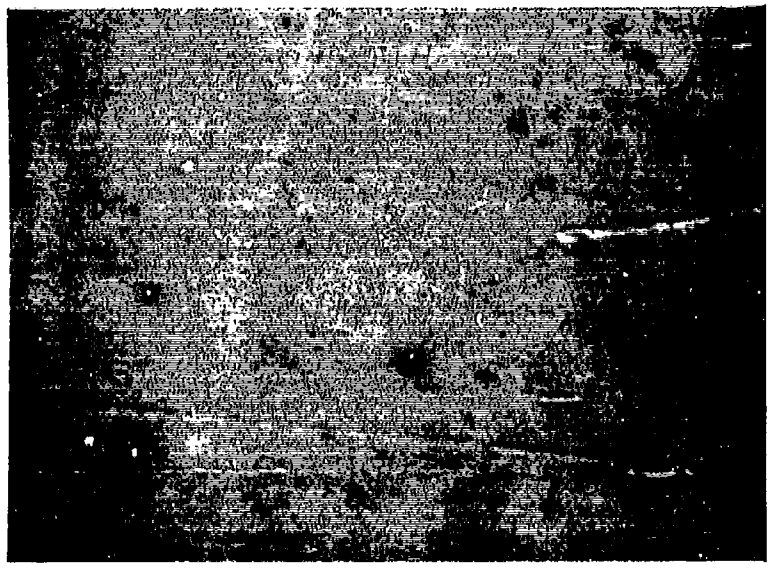
APPENDIX D-6
8-μm FILTRATION PHOTOMICROGRAPHS
BRAVE SHIELD XV—TANK TRUCKS

(See Table 10)



8μ 4X

SAMPLE 6652
Tank Truck No. 47
(Unfiltered)



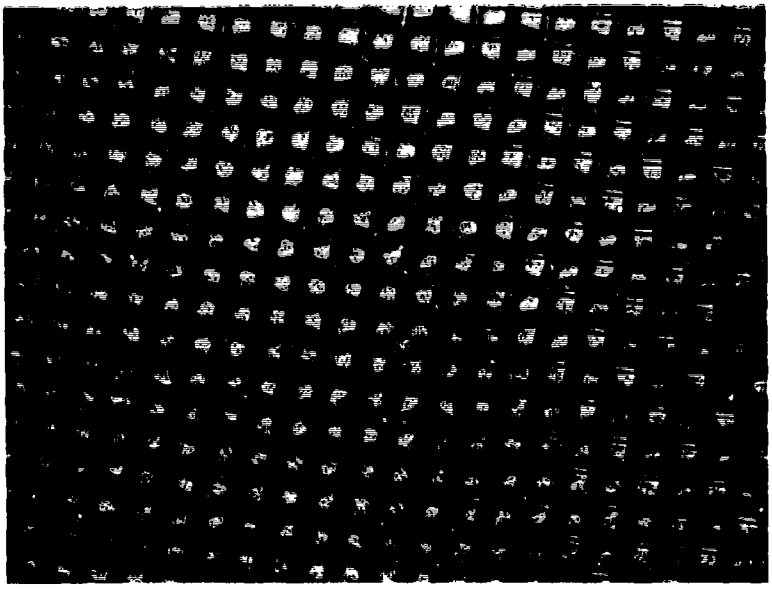
8μ 4X

SAMPLE 6653
Tank Truck No. 47
(After Filter)

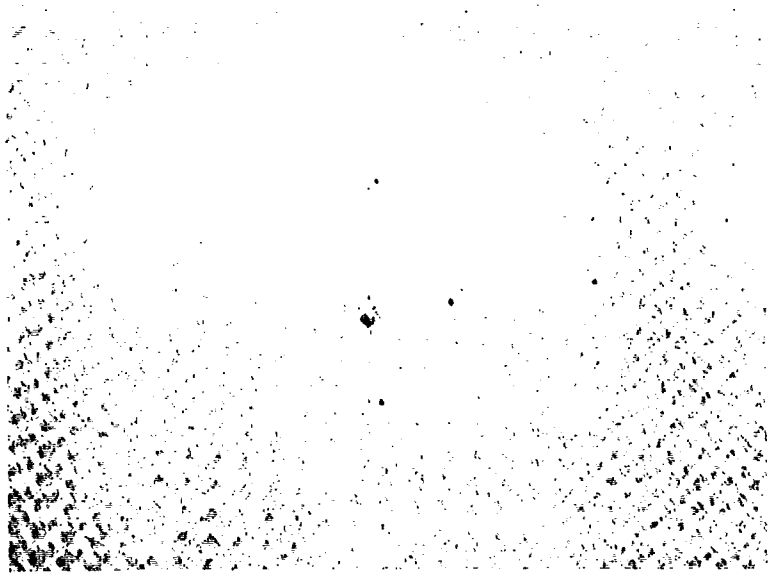
APPENDIX E
FILTRATION PHOTOMICROGRAPHS FOR OPERATION GALLANT CREW

APPENDIX E-1
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6895

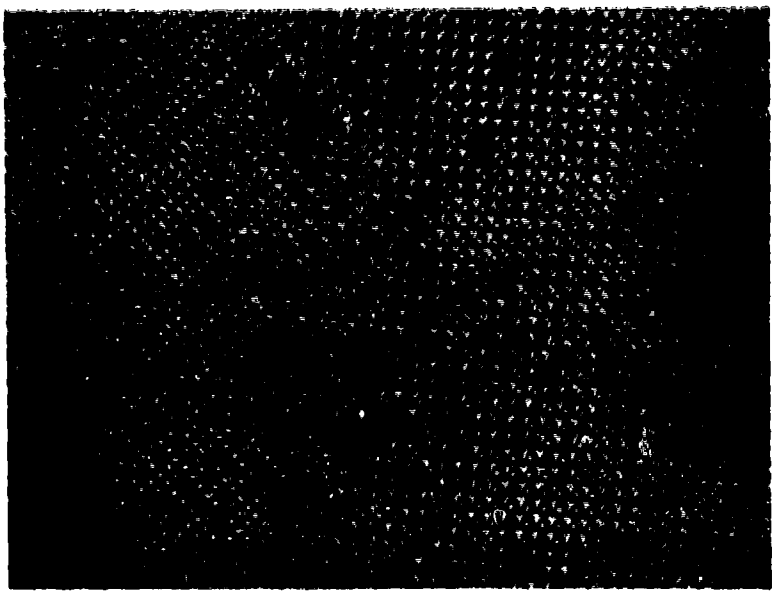
CH-47C, 70-15008 Left Front Drain
(See Table 13)



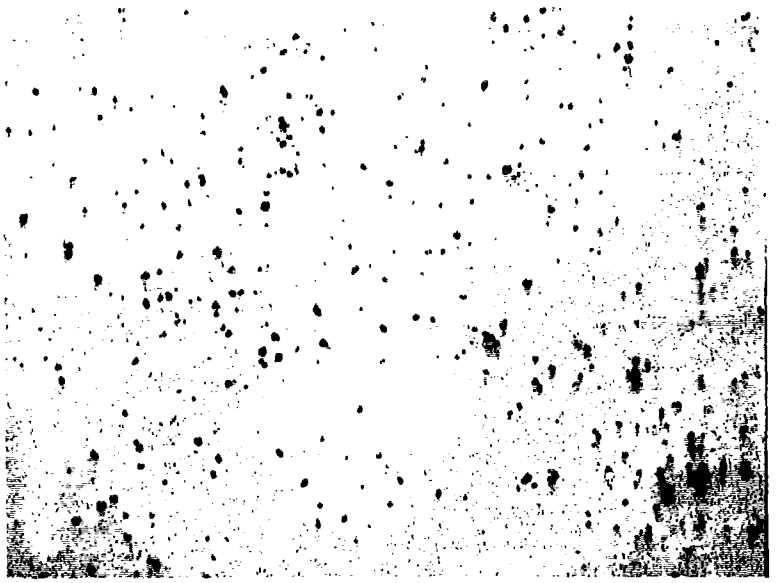
1000μm 4X



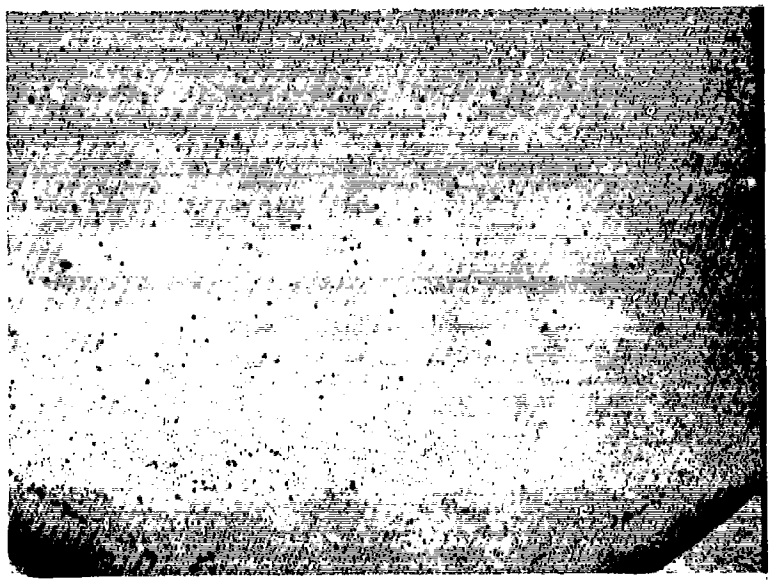
500μm 4X



300μm 4X



100μm 4X



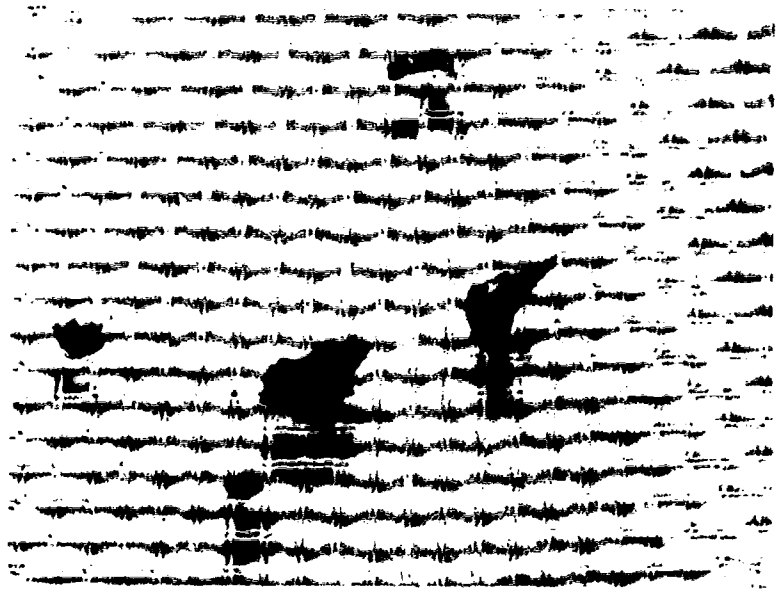
52μm 4X

26μm 4X

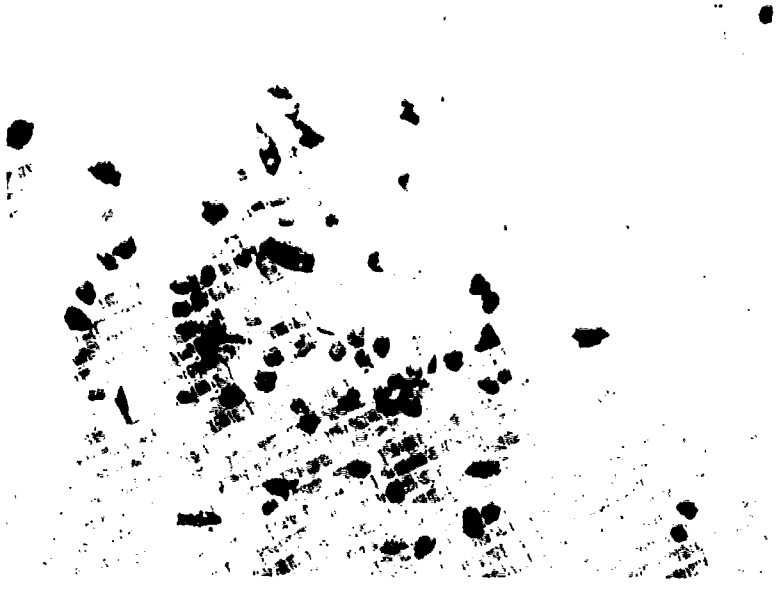
8μm 4X

APPENDIX E-2
CASCADE FILTRATION PHOTOMICROGRAPHS
SAMPLE NO. 6914

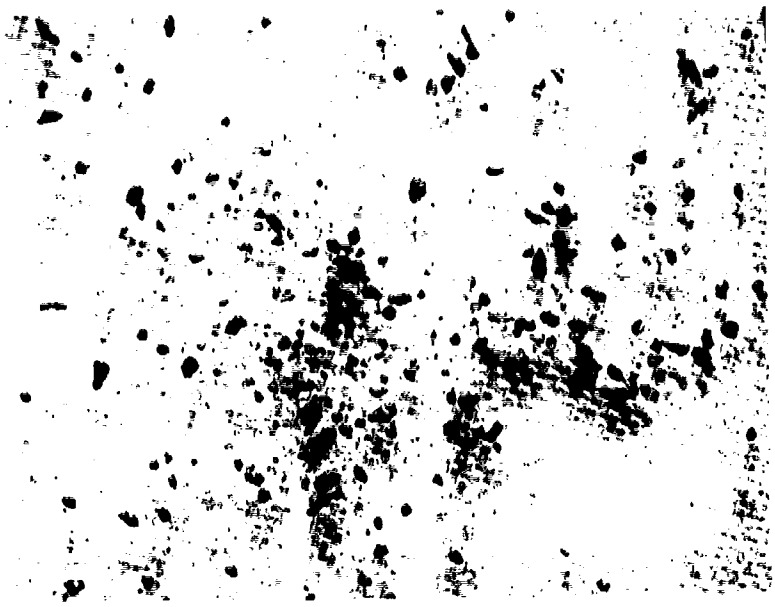
CH-47C, 70-15019 Right Front Drain
(See Table 13)



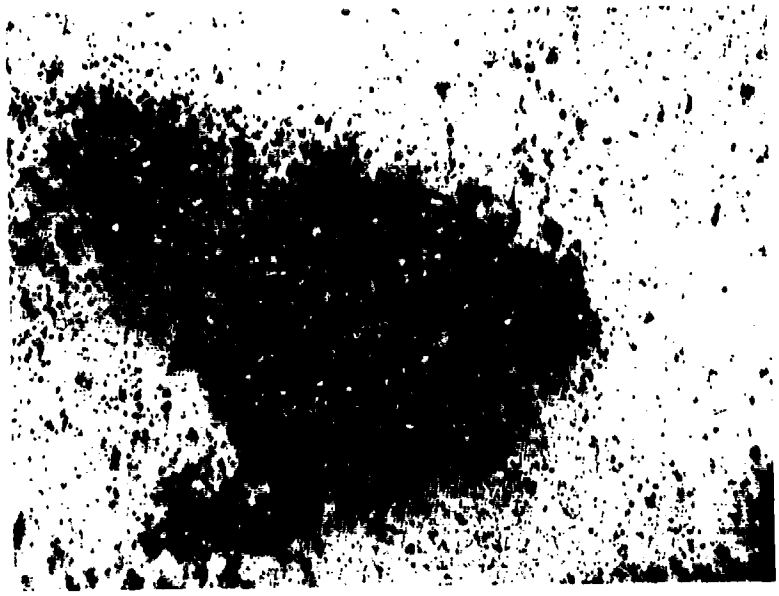
1000μm 4X



500μm 4X

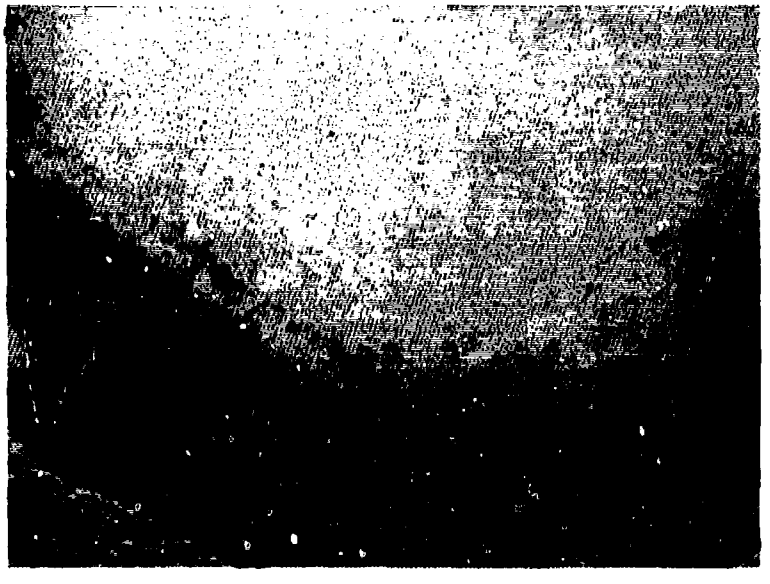


300μm 4X

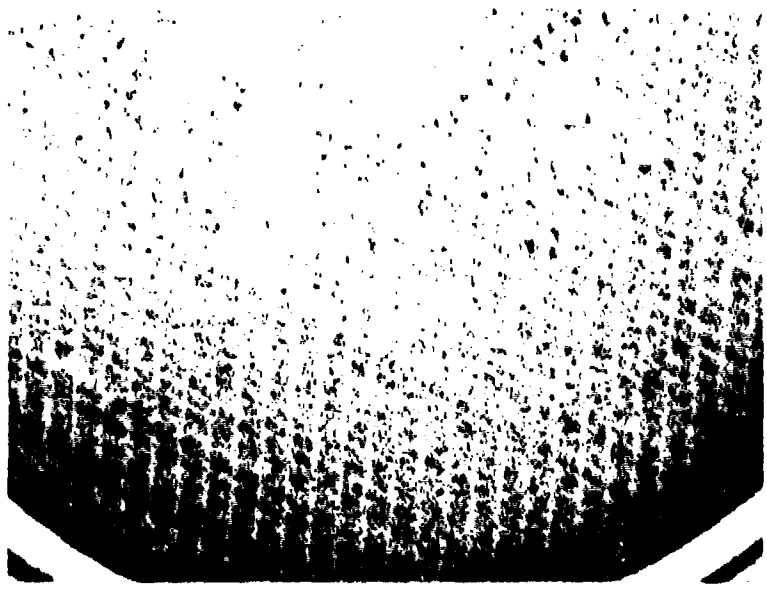


100μm 4X

52μm 4X



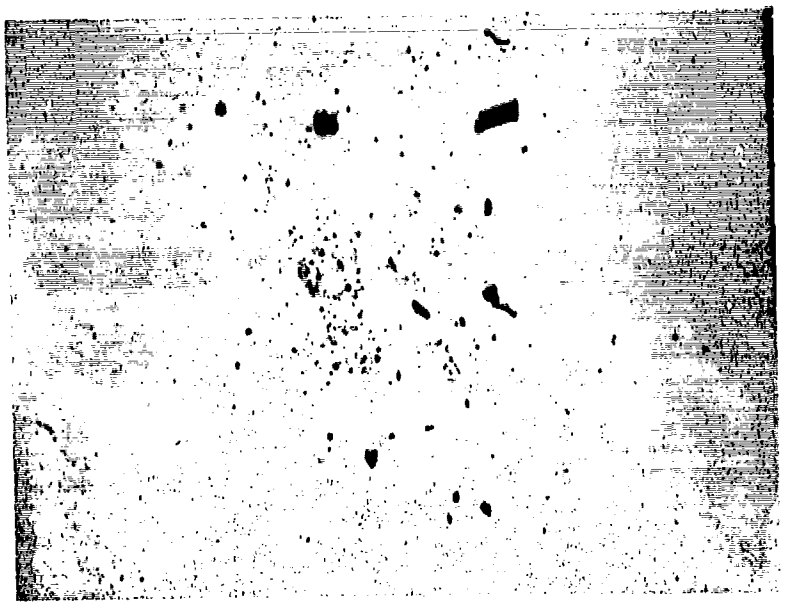
26μm 4X



8μ 4X

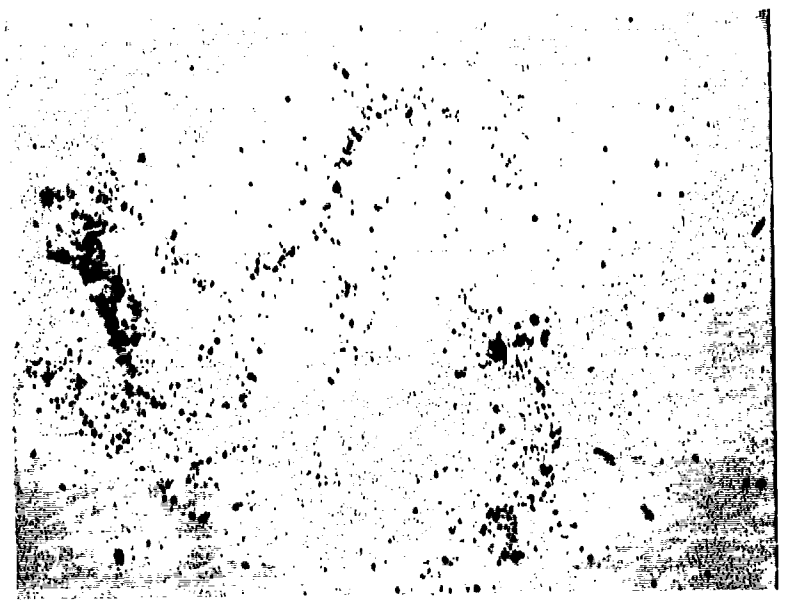
APPENDIX E-3
8-μm FILTRATION PHOTOMICROGRAPHS
GALLANT CREW–AIRCRAFT

(See Table 12)



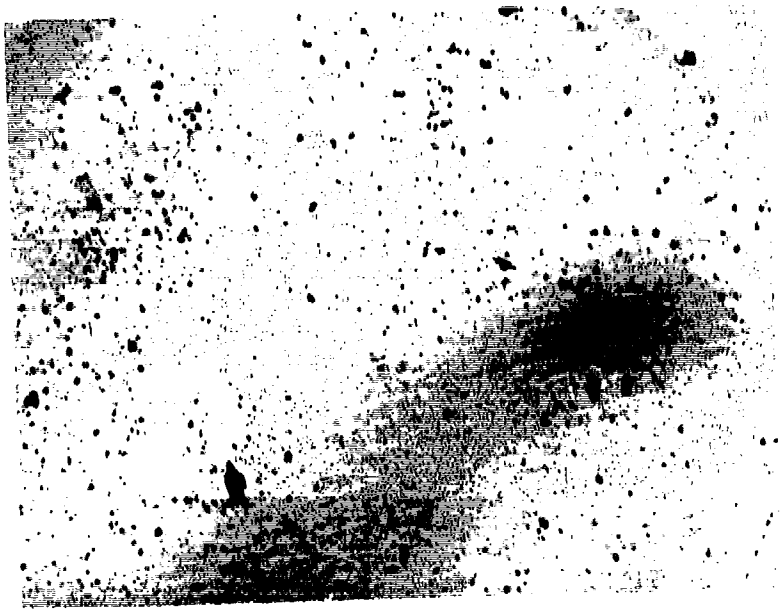
8μ 4X

SAMPLE 6890
UH-1H, 71-20223 (LF)



8μ 4X

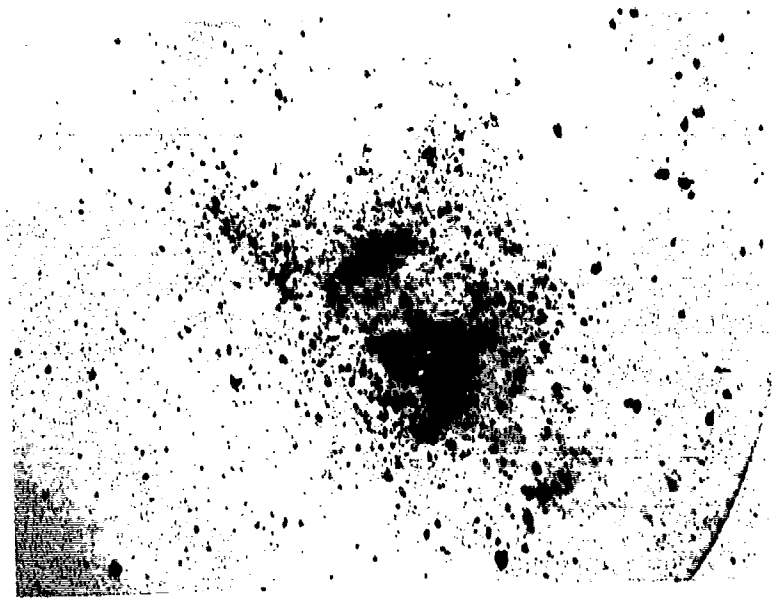
SAMPLE 6891
UH-1H, 71-20223 (RF)



8μ

4X

SAMPLE 6897
CH-47C, 70-15027 (LF)



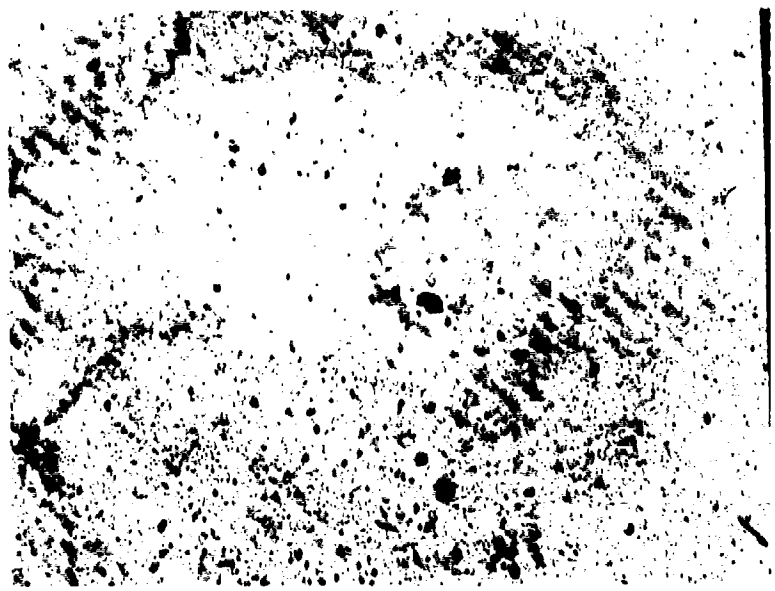
8μ

4X

SAMPLE 6898
CH-47C, 70-15027 (RF)

8μ 4X

SAMPLE 6915
CH-47C, 70-15019 (RR)



8μ 4X

SAMPLE 6916
CH-47C, 70-15019 (LF)

8μ

4X

SAMPLE 6917
CH-47C, 70-15019 (LR)

8μ

4X

SAMPLE 6885
OH-58A, 71-20554

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